ERRATA

p. 10, l.17	for <u>tufts</u> read <u>tuffs</u>
p. 68, l.12	insert the following: c) <u>Meltwater Channel Deposit Member</u>. This member has been mapped at a single locality along the western margin of the Mesopotamia basin. Remnants of seven one-sided meltwater channels are preserved ... "
p. 80, l.24	should read: "The exposure occurs beneath a small area of undulating ablation moraine."
p. 84, l.17-18	should read: "In the valley of Boundary Stream ..."
p. 123, l.3	insert the following: " ... landforms of successive ice fluctuations is not continuous over sufficiently large areas."
p. 162, l.6	for <u>patter</u> read <u>pattern</u>
p. 166, l.27	insert the following: " ... in Chapter 11 (p. 95)."
p. 175, l.18	should read: "At 0.3 km to the north is a belt of ablation moraine ..."
p. 194, l.28	should read: " ... the Burnham Formation extends 2.5 km westwards ..."

THE GLACIAL SEQUENCES IN THE RANGITATA AND ASHBURTON VALLEYS, SOUTH ISLAND, NEW ZEALAND

A thesis
submitted in fulfilment
of the requirements for the Degree
of
Doctor of Philosophy in Geography
in the
University of Canterbury

by

M.C.G. Mabin

University of Canterbury
1980

Frontispiece: "YE HORRIBYLE GLACIERS" (Butler 1862)

"THE CLYDE GLACIER: Main source of the River Clyde (Rangitata)". John Gully, watercolour 44×62 cm. Painted from an ink and water-colour sketch by J. von Haast.

Alexander Turnbull Library Wellington, N.Z.

This painting shows the Clyde Glacier in March 1861. It has reached an advanced position just inside the remnant of a slightly older latero-terminal moraine ridge that is visible to the left of the small figure in the middle ground. Ablation moraine covers the entire glacier surface, and an end moraine is forming around part of the snout. Meltwater is discharging from a tunnel at the base of the clean-ice zone.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

MAPS

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I would like to thank my parents for their encouragement and generous financial assistance during the early stages of this work.

Professor Jane Soons supervised this thesis. Her guidance and help with the field work and preparation of the text are greatly appreciated. The helpful discussions in the field with Dick Birnie, Peter Birkeland and Peter Oliver are gratefully acknowledged. My thanks also to David Bowen for his worthwhile criticisms of the early chapters.

Accommodation in the field was kindly provided by Messrs J. Acland, A. Deans, W. Dobbs and M. Prouting. My thanks go to them and the other farmers in the area who allowed me on their land.

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Numerous people helped to prepare this thesis. Jenny Penman drafted the maps and diagrams, Tish Gorton did the photographic work, and Mrs A. Dellow typed the manuscript. I am very grateful for their highly professional work. The help of many friends in the field work, colouring of maps, proofreading and as providers of good company over the years is also warmly appreciated. In particular I would like to thank Bob Kirk, who acted as a temporary supervisor, field assistant, reader of drafts and continual source of encouragement, but especially for his friendship and support over my years at Canterbury.

ABSTRACT

Extensive areas of glacial, fluvioglacial and associated landforms and deposits are preserved in the Rangitata and Ashburton Valleys. Geomorphologic and lithostratigraphic maps of this area are presented. Three main glacial sequences are identified: those formed by the main lobe and distributary lobe of the Rangitata glacier, and that associated with the combined Rakaia distributary lobe and Cameron glaciers. The smaller Ashburton glacial sequence is also mapped.

A sequence of five main Late Pleistocene glacial advances representing at least three glaciations can be recognised as follows (from youngest to oldest):

Spider Lakes/Lake Heron Advances
minor interstadial
Hakatere/Emily Advances
major interstadial
Trinity Advance
interglacial
Dogs Hill Advance
interglacial
Pyramid Advance

Analysis of a large area of deglacial landforms, formed during the retreat of the distributary lobe of the Rangitata glacier after the Spider Lakes Advance, allows a detailed pattern of deglaciation to be determined.

The fan surfaces of the southern part of the Canterbury Plains have also been studied to determine the relationship between them and the inland glacial sequences.

Good correlations can be proposed between these glacial sequences and others in the Canterbury region.

PART ONE: INTRODUCTION

CHAPTER 1

GENERAL INTRODUCTION

1. INTRODUCTION

Quaternary research in the South Island of New Zealand has focussed mainly on the effects of Pleistocene cold climates on the environment. A major aspect of this research has been the study of valley glacial sequences. This thesis presents the results of geomorphic investigations into the glacial sequences in the Rangitata Valley and the South Branch of the Ashburton River. (For convenience the South Branch of the Ashburton River will be referred to in this thesis as the Ashburton River.) These valley systems are shown in Figure 1. The study has involved analysis of glacial landforms in a 1500 km^2 area of the east-central section of the Southern Alps and foothill ranges. During the Late Pleistocene this area was occupied several times by large valley glaciers. These included the two lobes of the Rangitata glacier, a distributary lobe of the Rakaia glacier which coalesced with the Cameron Glacier, and the Ashburton Glacier, as well as many smaller glaciers in the foothill ranges. Four separate but interrelated glacial sequences have been studied in detail.

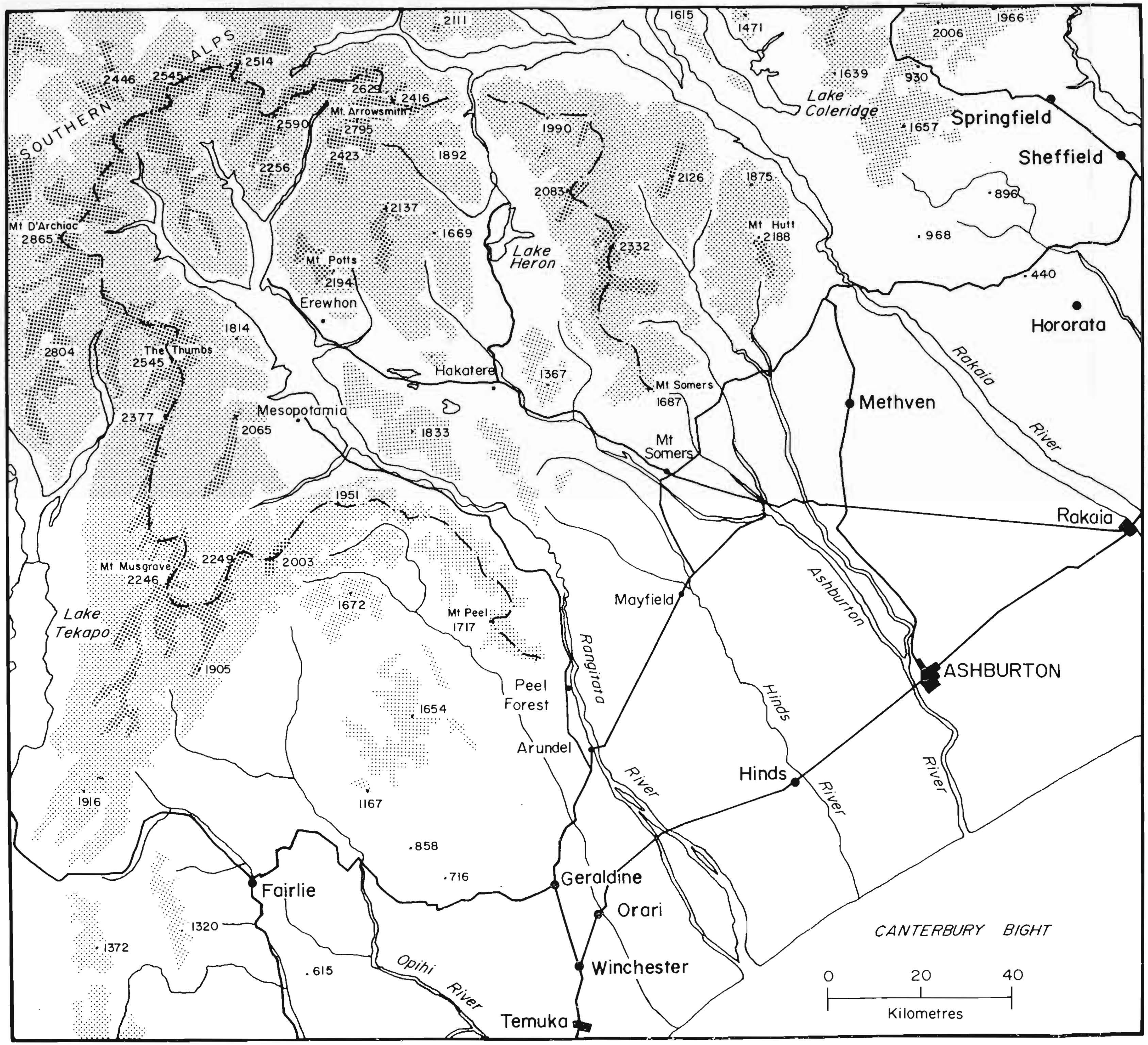
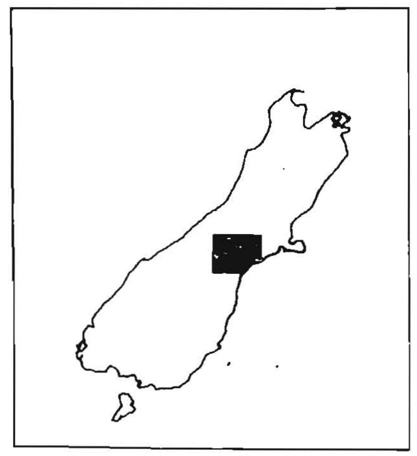


Figure 1: LOCATION MAP

—·— Upper catchment boundary of Rangitata, Sth. Branch Ashburton Rivers and Lake Stream.

1000 - 1800 m

1800 + m



2. SCOPE OF THE INVESTIGATION

The study of the glacial sequences in the Rangitata and Ashburton valleys has important ramifications in relation to the nature of the sequences, and the wider context of Quaternary research in New Zealand.

In the study area glacial and fluvioglacial deposits are very extensively preserved. In places detailed identification of landforms is possible. This has enabled an unusually complete determination of ice front behaviour and sedimentation patterns.

Research has been carried out in the Northern Hemisphere on landscapes formed during the deglaciation of the Laurentide and Scandinavian ice sheets. No such studies have been made in New Zealand largely because in valley glacial systems extensive areas of deglacial landforms are not usually preserved. However in the present study area 65 km^2 of these morphologies are preserved, giving a detailed record of part of the deglaciation from the last glaciation.

The Rangitata and Ashburton rivers flow to the South Pacific Ocean across the southern portion of the Canterbury Plains. These plains consist of large low-angle multi-storey alluvial fans. This study presents an opportunity to assess the relationship between a detailed glacial sequence and the alluvial fan surfaces of the Canterbury Plains.

This study is also important in a broader context. In recent years concepts of the Pleistocene glacial epochs have been radically altered. Multi-disciplinary research has revealed a much more complex pattern of climatic change than

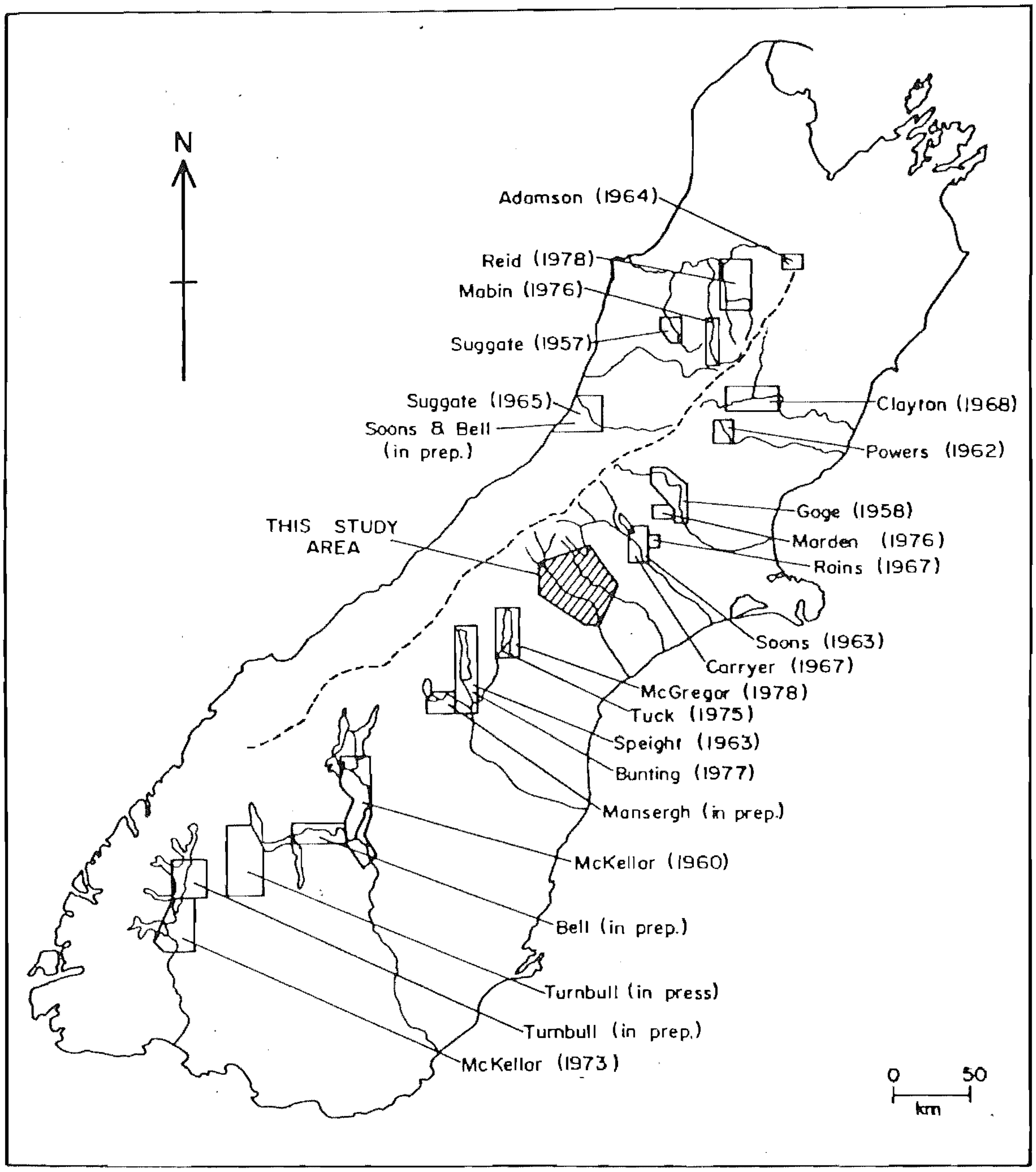


FIG. 2. : Other Late Pleistocene Glacial Sequences Studied in the South Island

had been previously accepted (Bowen 1978). The importance of data from terrestrial regions, particularly glacial sequences, in establishing chronologies has been questioned (*ibid.*). It is thus timely to consider a glacial sequence in the light of these changing perspectives of Pleistocene climatic oscillations.

The establishment and correlation of the glacial chronology in these valleys is a major aim of this study. Glacial sequences have been described from many alpine valleys, particularly east of the main divide of the Southern Alps (Fig. 2). The Rangitata/Ashburton sequences are centrally located in the South Island and are close to the important Waimakariri sequence (Gage 1958) which has been a model for most subsequent work on glacial sequences. They also form a potentially useful link, especially between the much studied Rakaia system to the north (Soons 1963, Carryer 1967, Rains 1967, Soons and Gullentops 1973) and the Mackenzie Basin sequences to the south (Speight 1963, Mansergh 1973, Tuck 1975, Bunting 1978).

Although many alpine valleys have been shown to have reasonably clear morphological glacial sequences, the establishment of a standard glacial chronology of the New Zealand Pleistocene has been difficult to achieve. The main problem lies in correlating sequences west and east of the Main Divide. The Glacial Chronology of the New Zealand Pleistocene, proposed by Suggate (1965), is based on the sequence of advances of the Taramakau glacier on the western side of the Main Divide. However, most of the sequences are on the eastern side. His chronology, and the trans-alpine correlations based on it, have been questioned by Soons (1966), Gage (1971), Gage and Soons (1973), Mabin (1976), and Bell (1977). Many more glacial sequences have subsequently been studied and a reassessment of Suggate's (1965) mapping is being carried out (Soons and Bell 1980). In the light of these considerations, changing views of the Pleistocene, and the nature of the glacial chronology described herein, a reassessment of Suggate's (1965) chronology is indicated.

3. THESIS LAYOUT

This thesis aims to describe the glacial and fluvioglacial landforms of the Rangitata and Ashburton river valleys, to define a sequence of glacial advances and to propose a glacial chronology which can be correlated with other South Island glacial chronologies.

The thesis is subdivided into four parts. Part One is introductory, dealing with the geologic and physiographic background, previous work, methodology and criteria for differentiating glacial advances. Part Two gives a general description of the glacial and fluvioglacial landforms and deposits. Part Three examines the three main glacial sequences in detail, and the Canterbury Plains. In Part Four a glacial chronology is presented and correlated with other South Island glacial chronologies.

CHAPTER 2

GEOLOGIC AND PHYSIOGRAPHIC BACKGROUND

1. INTRODUCTION

During the Late Pleistocene glaciations the pattern of glacial systems that developed was largely controlled by physiographic setting. The broad elements of the landscape are geologically controlled. The major rock type is greywacke. The extensively faulted and jointed nature of this rock makes it very susceptible to physical breakdown, particularly by frost shattering. Vast amounts of gravel material were thus available to be deposited during the glacial periods. However, the main geological influence on the physiography is structural. The configuration of river valleys, mountain ranges and intermontane basins is controlled by a complex fault system.

2. GEOLOGIC SETTING

The geology of the area is relatively simple and is shown in Figure 3. Mesozoic greywackes and argillites are overlain by a Late Cretaceous volcanic suite. In turn, these are both overlain by Late-Cretaceous-Upper Tertiary marine and non-marine sediments.

The Mesozoic greywackes and argillites of the Canterbury Suite (Andrews *et al.* 1976) outcrop over most of the field area. They consist of weakly metamorphosed sandstones and siltstones, with minor conglomeratic lenses (Oliver 1979). These sediments, which are well indurated and have undergone several phases of orogenic folding and faulting, range in age from Middle Triassic to Upper Jurassic (Oliver 1979, Rettalack 1979).

Upper Cretaceous volcanic rocks overlie these Mesozoic strata. They outcrop along the inner margin of the Canterbury Plains and consist of terrestrial rhyolites and andesites. Although faulted and tilted in places these rocks are largely undeformed (Oliver 1979).

A sequence of Upper Cretaceous to Mid-Tertiary marine and non-marine sediments overlies the Cretaceous volcanics. They outcrop mostly along the inner plains margin, but scattered inliers also occur further inland (Mason 1947, 1948, Gair 1965a,b, 1968, Beggs 1978). These sediments include coal measures, silica sands, tufts and limestones. In some places strongly weathered non-marine greywacke gravels unconformably overlie the earlier Tertiary strata. These gravels, which outcrop in Forest Creek, Harper Range (Gair 1968) and Mt. Somers (Speight 1938, Gregg 1978), are correlated with the Kowai Formation in North Canterbury of Wilson (1963). They are probably Upper Pliocene-Lower Pleistocene in age.

Late Pleistocene deposits can be seen to unconformably overlie all the lithologies described above. They can be distinguished from the older Kowai Formation gravels by a lack of tilting or folding and less weathering as the older gravels have manganese staining on many of the clasts.

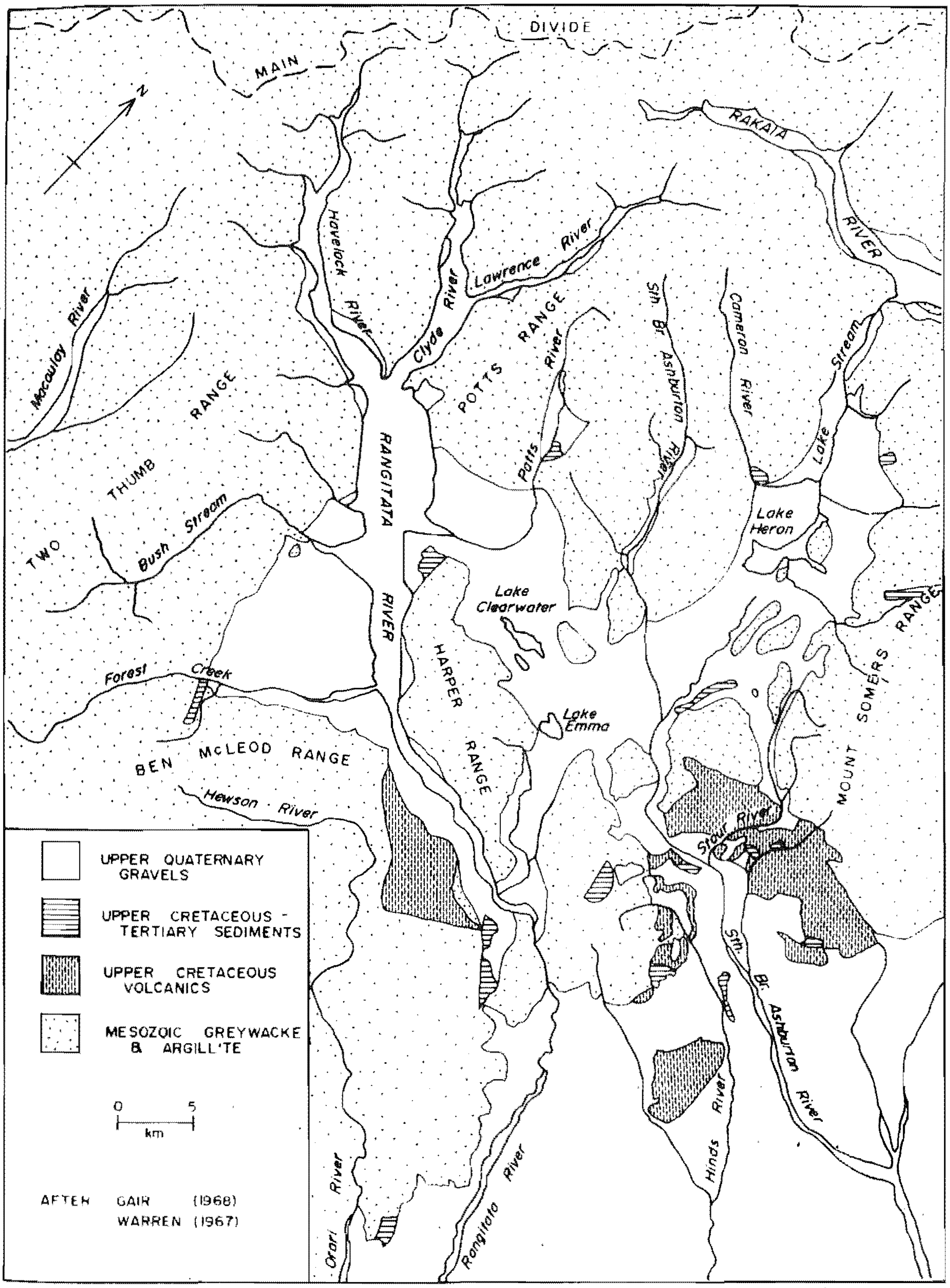


FIG. 3. : Generalised Geological Map

From Figure 3 it can be seen that the dominant element of the geology is the greywacke and argillite terrain of the Canterbury Suite. A volcanic suite is common along the inner plains margin where isolated outcrops of Tertiary strata can also be seen. However, the major geological influence on the landscape is structural. "All the major valleys and ranges in the area appear to be bounded by faults related to the Kaikoura Orogeny" (Oliver 1979, p. 110).

3. LATE CENOZOIC DEVELOPMENT OF THE STUDY AREA

The major influence on the Late Cenozoic development of the study area has been the Kaikoura Orogeny which began sometime after the mid-Miocene (Oliver 1979) and continues to the present day (Suggate 1978). The orogeny probably did not begin to reach a climax until later in the Pliocene or early Pleistocene when the non-marine Kowai Formation was deposited. This is believed to represent remnants of a piedmont apron of coalescing alluvial fans deposited to the east of the rising Southern Alps (Gregg 1978).

The Kaikoura orogenic movements can be divided into three zones (Suggate 1978, Fig. 10.2).

i) Alpine Uplift Zone.

This zone covers the high mountains of the upper catchments of the Rangitata and Ashburton rivers, and extends east from the main divide for 30 km. The area is characterised by rapid rates of uplift. Total Kaikoura orogenic uplift has probably been in the order of 20,000 m (Suggate 1963a) at rates of 5-10 mm per year (Wellman 1979).

ii) Fault-Fold Zone.

This covers the intermontane basins and foothill ranges that lie to the east of the Alpine Uplift zone. In this region differential uplift and block faulting during the Kaikoura Orogeny have formed a landscape of fault bounded basins surrounded by upthrust foothill ranges. Rates of uplift range from 2 - 0.5 mm per year (Wellman 1979).

iii) Canterbury Plains Subsidence Zone.

This extends east from the inner plains margin for 50 km to the coast. Throughout the Kaikoura Orogeny this area has been subsiding at 0.1 - 0.2 mm per year (Wellman 1979). Quaternary gravel deposits over 700 m thick have accumulated in this slowly subsiding basin (Atkins and Hicks 1977).

From this it can be seen that the main features of the physiography of the Rangitata and Ashburton catchments result from Kaikoura orogenic movements. The main elements of the landscape were probably in existence by the Late Pliocene (Suggate 1978). Since this time, continuing tectonic activity and repeated glaciations have served to shape the present landscape and give it its particular character.

4. PHYSIOGRAPHIC BACKGROUND

The Rangitata and Ashburton catchments stretch south-eastwards for 125 km from the main divide of the Southern Alps to the seaward margin of the southern Canterbury Plains. The southern inland boundary is formed by the Two Thumb Range and Ben McLeod range, and passes through the mountain massif of

Coal Hill to Mt. Peel on the inner margin of the plains. The northern boundary passes east from the main divide along the Wildman's Brother Range, then south through the Palmer, Taylor, Mt. Somers and Winterslow Ranges to Mt. Somers which rises above the inner plains margin 35 km north-east of Mt. Peel (Fig. 1).

The Rangitata and Ashburton catchments may be divided into three distinctive physiographic regions: alpine, foothill ranges and intermontane basins, and the plains. These are shown on Figures 4 and 5.

i) Alpine Region.

The Alpine Region extends approximately 35 km south-east from the main divide. It is characterised by steep, rugged greywacke mountain ranges that are traversed by deeply incised river courses. The mountains along the divide, which support many small glaciers, rise to 2545 m (Newton Peak). The ranges that extend east and south from the main divide also support small glaciers, and rise to 2795 m (Mt. Arrowsmith).

Two major rivers flow south-south-east through this region. The Havelock and Clyde Rivers, whose valley floors are up to 2.3 km wide, are cut 1250 m below the level of the surrounding mountains. They rise in numerous small glaciers from along 35 km of the main divide, and join 21 km downstream to form the Rangitata River.

Four other large rivers also rise in this Alpine Region: the Lawrence, Potts, South Branch of the Ashburton and the Cameron. They all rise in the Arrowsmith Range, 15 km east from the main divide. The valley floors are less

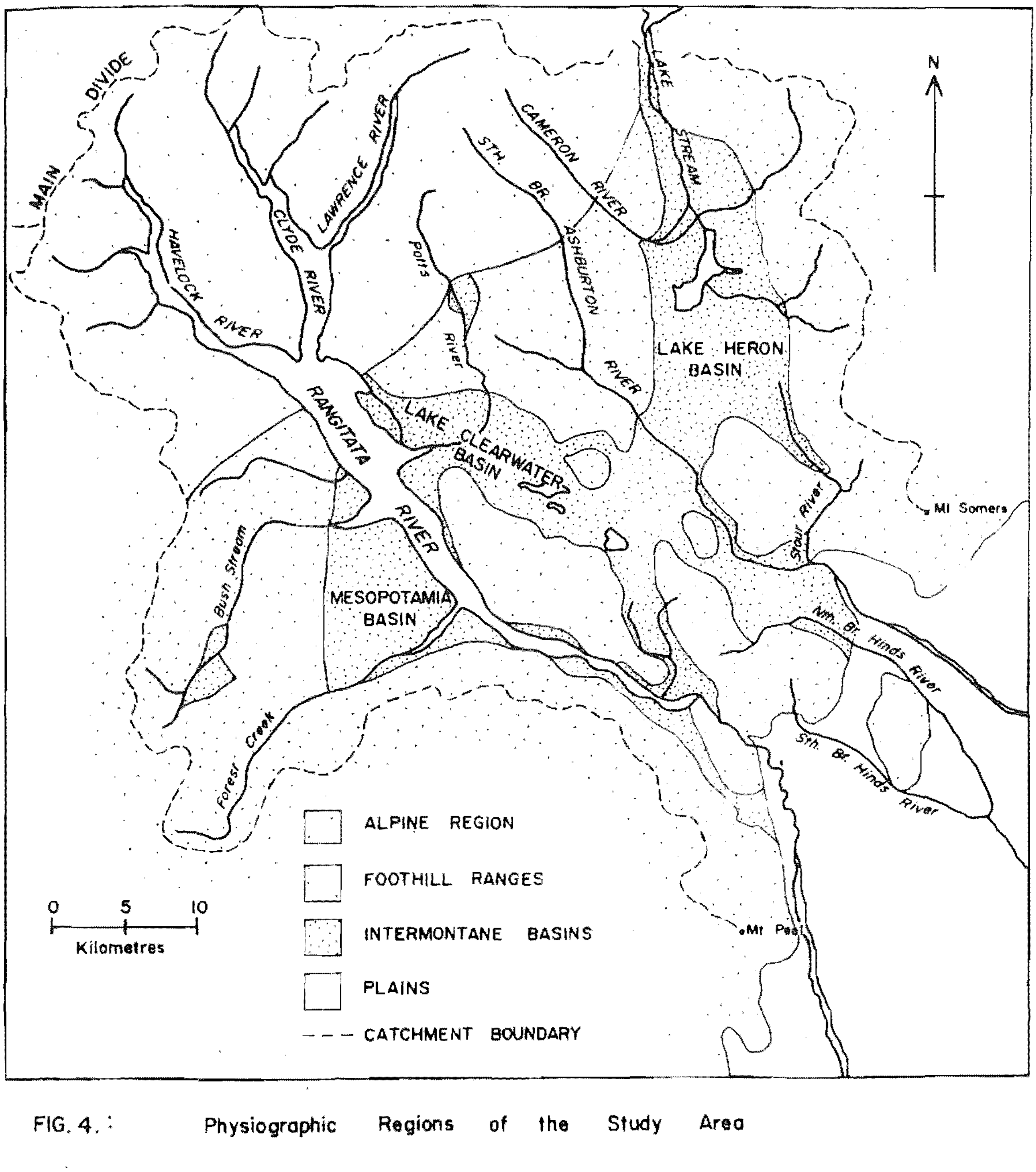


FIG. 4.: Physiographic Regions of the Study Area

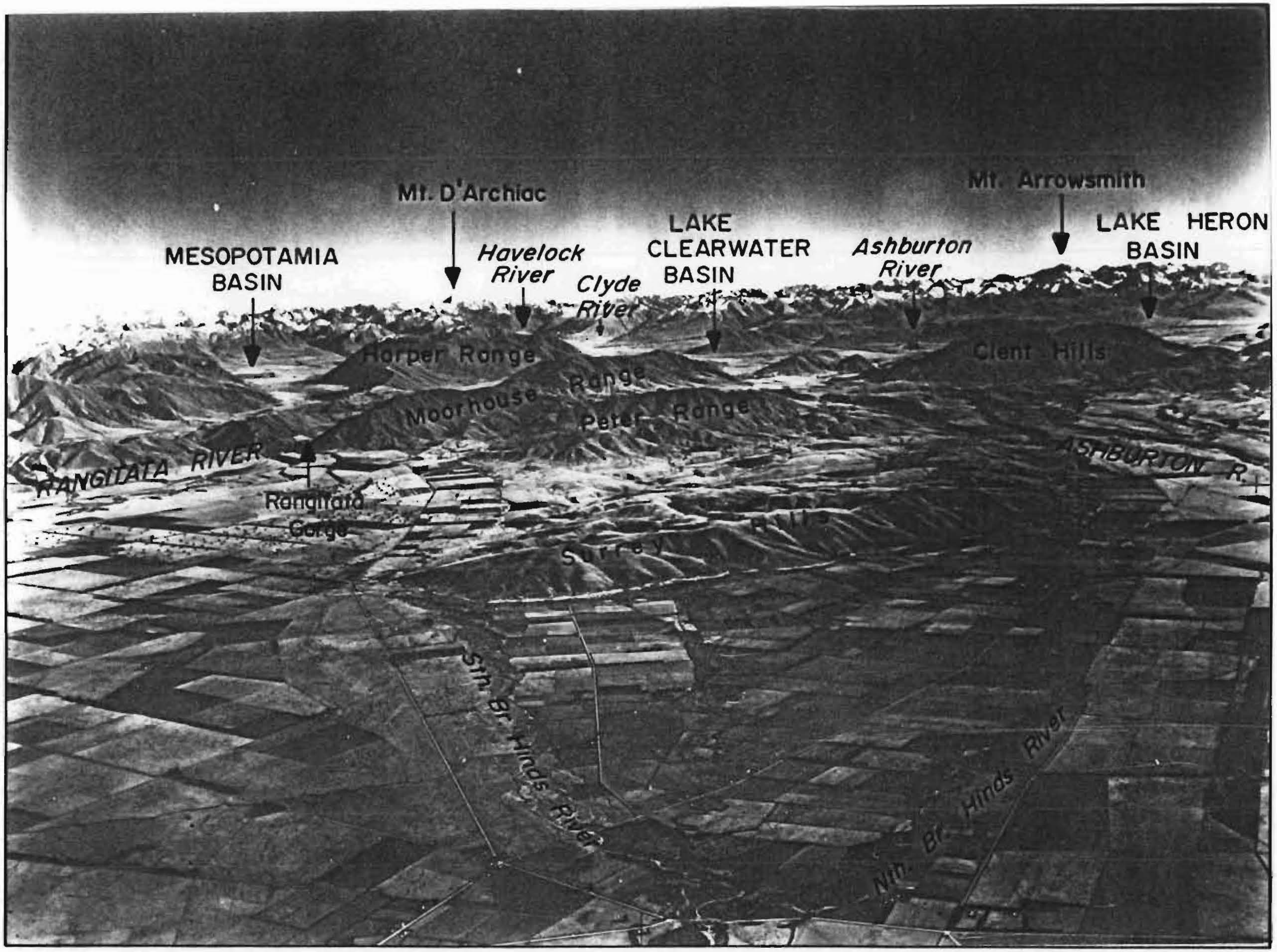


FIG. 5. Oblique Aerial View of Study Area

N.Z. Aerial Mapping Limited, Hastings.
Book 8, Neg. 1508.

than 0.75 km wide and are entrenched up to 1250 m below the level of the surrounding mountains. The Lawrence River flows for 21 km south-west from its glacier source on the western side of the Arrowsmith Range to join the Clyde River. The Potts River rises in the south of the Arrowsmith Range and flows 30 km south-south-east to join the Rangitata River. The Ashburton and Cameron Rivers flow from small glaciers on the eastern side of the Arrowsmith Range. The Ashburton River flows south-east for 26 km to enter the southern part of the Lake Heron basin. The Cameron River flows 16 km from its source into the northern part of the Lake Heron basin where it joins the Lake Stream, a tributary of the Rakaia River.

This high alpine zone has formerly been extensively glaciated. Many classic features of glacial erosion can be recognised: cirque basins, truncated spurs, hanging valleys (Speight 1923), and over-steepened valley sides. This, and the fact that during the glacial periods much of the zone would have been above the regional snowline, has resulted in very few glacial deposits being preserved. Many of the cirque basins are still occupied by small glaciers. There are 22 named glaciers, the largest being the 4.5 km long Colin Campbell Glacier at the head of the Clyde River. Holocene moraines can be seen up to 11 km down valley from some of these glaciers (Burrows and Gellatly, *in prep.*). Further east from the main divide, outside the area of present day glaciation, several of the cirque basins contain rock glacier deposits. However it is not known how many of these are still active. A number of postglacial alluvial fans and landslide deposits are present in the Alpine Region. They are generally heavily truncated and are in the process of being eroded away by the main rivers. The commonest depositional landforms in the mountains are screes. They are especially common above 1250 m altitude. Other associated landforms, pro-talus ramparts and avalanche cones can also be recognised, but are not common.

This Alpine Region was the source area for the Late Pleistocene glaciers that extended down all the main river valleys into the intermontane basins.

ii) Intermontane Basins and Foothill Ranges Region.

The intermontane basins and foothill ranges occupy the central portions of the Rangitata and Ashburton catchments. This area consists of broad, generally flat floored basins that are flanked by rugged greywacke mountain ranges. Several large rivers flow through the basins, and a number of smaller rivers rise in the foothill ranges. The depressions can be as low as 610 m above sea level (a.s.l.), but average 750 m - 830 m a.s.l. The surrounding foothill ranges are generally 600 m higher, averaging 1220 m - 1370 m a.s.l. The highest peaks are Captains Peak, 2377 m (Two Thumb Range) and Mt. Taylor, 2330 m (Taylor Range), however some of the foothill ranges near the inner plains margin are only 1070 m a.s.l. (Peter Range).

Three main intermontane basins can be identified: the Lake Heron, Lake Clearwater and Mesopotamia basins. The north-south trending Lake Heron basin is 30 km long and up to 10 km wide. The Lake Clearwater basin, which trends north-west to south-east, is 20 km long and 6 km wide. The Mesopotamia basin is a triangular shaped area 20 km long and up to 10 km across. There are also two smaller basins. The Pudding Valley basin is 2.5 km wide and runs south from the eastern end of the Clearwater basin for 9 km to the Rangitata Valley. The Whiterock depression extends south from the Rangitata Valley 2 km to the west of and above the Rangitata Gorge. This is a fault angle-depression (Mason 1947) 1.2 km wide, 10 km long and it issues onto the plains at Raules Gully, some 4.5 km down valley from the Gorge.

The intermontane basins and foothill ranges are drained by a number of rivers. The Rangitata, Potts, Ashburton and Cameron Rivers, which rise in the Alpine Region, flow across the main basins. The Rangitata and Ashburton Rivers flow through short gorges cut through the foothill ranges before issuing onto the plains (see Fig.23). Several smaller rivers rise in the foothill ranges. Bush Stream and Forest Creek drain from the Two Thumb Range. The Lake Stream, Smite, Swin and Stour Rivers rise in the ranges on the eastern margin of the study area, while the Hinds River drains from the Moorhouse and Peter Ranges. The intermontane basins which contain numerous small shallow lakes are drained by minor streams. The Lake Clearwater basin is drained by Lambies Stream, and the Lake Heron basin by Gentleman Smith Stream.

Most of this region was extensively glaciated during the Late Pleistocene. Most of the inland foothill ranges supported cirque and small valley glaciers. These were most extensive in the Two Thumb Range. The intermontane basins were occupied by large glaciers from the Alpine Region. These basins contain a wide array of glacial and associated deposits. These deposits are also preserved on the flanks of the foothill ranges that surround the intermontane basins.

The deposits preserved in this region are mapped and discussed in this thesis.

iii) Plains Region.

The Plains Region forms the largest part of the Rangitata and Ashburton catchments, being 55 km long and 45 km wide. It extends north-eastwards from the southern boundary along Coopers Creek to the North Branch of the Ashburton River. The inland boundary is marked by the downstream ends of the Rangitata and Ashburton Gorges and the Surrey Hills range. This Plains Region consists of two very large, coarse greywacke gravel alluvial fans that have been built up by the Rangitata and Ashburton Rivers. The small Hinds River flows along the junction of these two fans. The Rangitata River is entrenched up to 60 m below the general level of the plains and is flanked by numerous terraces especially along the reach north of Peel Forest. The Ashburton River is smaller and does not have the prominent terrace flights. It is only entrenched 10 m below the level of the plains.

The Plains were formed in the Late Pleistocene during phases of sedimentation related to the glacial advances further inland. Earlier during the Late Pleistocene the Rangitata and Ashburton glaciers may have extended onto the inner plains margin, however apart from this the area has been ice free.

The relationship between the plains surfaces along the inner plains margin and the inland glacial sequences is discussed in this thesis.

5. CONCLUSION

The geomorphology of the study area has been influenced by a long history of rapid orogenic uplift and repeated glaciation during the Pleistocene. The major elements of the landscape; the mountain ranges, intermontane basins and plains regions, result from the pattern of uplift during the Kaikoura Orogeny. However, the detailed characteristics of the physiography result from the effects of large ice age glaciers on the landscape.

CHAPTER 3

PREVIOUS WORK

1. INTRODUCTION

In the study area there has been little research in the field of Quaternary Studies. Early workers described various aspects of the glacial geomorphology, but made no attempt to define a Pleistocene glacial sequence. More recent research has covered aspects of the hard rock pre-Quaternary geology, soils, vegetation and hydrology.

2. PREVIOUS GLACIAL GEOMORPHOLOGY

Previous work on the glacial geomorphology of the area has had little direct bearing on this study. Although some of the glacial features have been described, no attempt has been made to systematically map the area or define a sequence of Late Pleistocene glacial advances.

The extensive Pleistocene glaciation of the area was first reported by Haast (1864a). In subsequent writings (Haast 1864b,c, 1879) he provided a wealth of descriptive information on the past and present glacial activity. He also provided the first map of some of the moraines in the vicinity of Lake Emma (Haast 1877). Further brief descriptions and maps of the glacial features were given by McKay (1878) and Cox (1884).

The most detailed published descriptions of the glacial geomorphology have been those of Speight (1907, 1923, 1938, 1941) and Speight *et al.* (1911). Although a wealth of descriptive data was presented, no attempt was made to define a sequence of Pleistocene glacial advances and only a small part of the area was mapped (Speight 1938).

More recently, research on the Pleistocene glacial deposits was undertaken by Keene and briefly reported in Burrows *et al.* (1974) and Burrows (1975). Mr Keene kindly made available his field notes and preliminary map of Sheet S/81.

The Holocene activity of the glaciers at the headwaters of the Rangitata, Ashburton and Cameron rivers has been reported by a number of writers (Haast 1864a,b,c; Acland 1892; Speight 1907, 1911). Haast, during his 1861-1862 explorations of this area, executed a number of pen and wash sketches of the Clyde and Ashburton glaciers. These were subsequently painted by John Gully and accompanied the Haast 1864a article (Paul 1974) (see frontispiece). Holocene glacial sequences have been described for the Ashburton, Cameron and Lake Stream valleys (Burrows and Russell 1975, Burrows 1975). Similar sequences were also being studied in the Havelock, Clyde and Lawrence valleys (Burrows and Gellatly, *in prep.*).

3. OTHER RELATED RESEARCH

Other recent research in the general field of Quaternary Studies has covered aspects of the palynology and soils of this area. Research on the palynology and post-glacial vegetation succession is being carried out by Russell (*in prep.*). Soils in the Paddle Hill Stream catchment, Mesopotamia and Waikari Hills Stations have been studied and mapped by Harvey (1974) and by Tonkin (*pers. comm.*). Hydrological studies have also been carried out on the Rangitata River (Walsh 1975, Fancourt 1976), and Ashburton Rivers (Cuff 1977, Fancourt 1977).

Geological mapping of the area was begun by Haast (1877). This, and subsequent work by Haast (1879), McKay (1878), Cox (1884), Speight (1938), Mason (1947, 1948) and Gair (1965a,b), provided a framework for the 1:250,000 scale N.Z. Geological Survey (Gair 1968). This map shows the glacial deposits in a general fashion. Since 1968, further geological studies have been carried out by Cambell and Force (1972), Beggs (1978) and Rettalack (1979). However the most detailed work has been that of Oliver (1977, 1979), Oliver *et al.* (1979) and Adams and Oliver (1979), which has covered largely the Mesozoic geology of Sheet S/81.

4. CONCLUSION

The present study can therefore be viewed in the context of this body of previous research. In describing and mapping the glacial and associated landforms it extends the work of Haast and Speight, and in describing a glacial sequence it expands the Holocene glacial chronologies of Burrows. This study can also be seen as a logical conclusion to the detailed geological mapping of Oliver and can be linked to studies in related fields of palynology, hydrology and soil science.

CHAPTER 4

MAPPING STYLES

1. INTRODUCTION

Most of the information on the glacial, fluvioglacial and associated features in the study area is contained in the thesis Maps 1-8. The construction of these maps is described in Chapter 5. This chapter deals with the mapping styles, classification systems, and units used to depict these glacial and associated features. The main concerns were to provide clear and coherent maps that reflect the nature of the field area, and to use a classification system that was consistent with previous work in this field.

2. NATURE OF THE FIELD AREA

An important influence on the mapping was the large size of the field area. Evidence for four separate but inter-related glacial sequences is contained in an area of over 1500 km^2. The Rangitata and Ashburton sectors of the Canterbury Plains cover a further 1500 km^2. It should be possible to correlate these glacial sequences with each other and with the surfaces of the plains.

There is evidence for multiple glaciations in the study area. This is principally morphological and although the lack of forest cover means the landforms can be easily seen, preservation is variable. The older features have been dissected and fragmented, making interpretation difficult. However, the landform style associated with the younger advances is that of extensively preserved and largely unmodified morphologies. Hence detailed interpretation of these features is possible. Unfortunately exposures are rare, thus detailed lithostratigraphic interpretations have not been possible. The sequence of glacial events has been elucidated largely on the basis of morphologies.

The thesis maps are therefore attempts to synthesize information from a wide area, to describe the nature of and interrelationships between the various glacial sequences and plains surfaces, and to present where necessary detailed coverage of critical areas. The full range of data collected in the field could not not be presented on one set of maps. To provide an overview of the whole study area, 1:50,000 scale stratigraphic maps have been drawn (Maps 1-4, 8). For selected areas where detailed identification of landforms is possible, 1:25,000 scale geomorphological maps are presented (Maps 5-7).

3. STRATIGRAPHIC MAPS

i) Introduction

No consistent approach to the mapping of glacial deposits has developed in New Zealand. However, Suggate (1965) and Gage (1977) recommended lithostratigraphic mapping. This was also recommended by the American Commission on Stratigraphic Nomenclature (1959). In the International

Stratigraphic Guide (Hedberg 1976) the Quaternary was recognised as a special field of stratigraphy (*ibid.*, p. 1) but it received no direct attention. However, it was implied that lithostratigraphic classification based on indirect evidence, such as geomorphic expression, was possible (*ibid.*, p. 39). This standpoint has been adopted by the Stratigraphic Commission of the International Union for Quaternary Research (Bowen 1978). It would appear that for Pleistocene glacial and fluvioglacial deposits the formation should function as the primary unit of stratigraphy (*ibid.*) and that mapping should preferably be lithostratigraphic although the distinguishing criteria for such units may not be always lithologic and may include such factors as their surface form (Gage 1977). This approach has been followed on Maps 1-4, and 8. It provides for continuity with other workers in this field (Suggate 1965, McKellar 1973, Turnbull, *in press*, *in prep.*) and also with the pre-Quaternary mapping in the field area of Oliver (1977, *in prep.*).

ii) Maps 1-4, and 8.

Maps 1-4 at a scale of 1:50,000 are lithostratigraphic maps of the Late Pleistocene deposits in the foothill ranges, intermontane basins and inner plains margin. The various deposits formed during each glacial event are grouped together in formations, with individual members being mapped where possible. The two basic members of a formation are the till and outwash deposit, which separates glacial from fluvial deposits. Other members include meltwater channel, alluvial fan, landslide, rock glacier, alluvium, swamp, and lake bed deposits.

Late Pleistocene deposits are not well exposed in the study area so that in many places lithology has been inferred from surface form. In view of this, and because a representative suite of exposures of the members of each formation is not available, type sections have not been identified and thus formations are only informally defined.

Suggate (1965) and Gage (1977) recommend that separate terminologies should be used for glacial sequences in individual catchments. Two large glacial catchments are mapped in this study; the Rangitata and Ashburton catchments. During the older advances the various glaciers coalesced, therefore these deposits were mapped using the same formation names. However during the younger advances the ice streams remained separate, thus separate formation names for these deposits have been used in each catchment (see Table 2).

The plains sector of the Rangitata and Ashburton Rivers is partly mapped on Maps 3 and 4, and fully mapped at a 1:250,000 scale on Map 8. The relationship between the deposits of the plains area and foothill ranges-intermontane basins area is unclear. Thus the use of the same terminology for these two areas is considered inappropriate. Plains formation terminology follows that established to the north for the Waimakariri and Rakaia River sectors of the Canterbury Plains (Suggate 1958, 1963b, 1965, 1973; Gregg 1964).

4. GEOMORPHOLOGICAL MAPS

i) Introduction

In several areas detailed identification of glacial and fluvioglacial landforms has been possible. Mapping at a larger scale is thus required. At such a scale, and in the absence of numerous exposures, lithological interpretation is impossible. Thus, on these maps landforms are depicted. The nomenclature of these morphologies is defined in Chapter 13.

ii) Maps 5-7.

Maps 5-7 are 1:25,000 scale geomorphological maps. They cover the areas at the head of the Rangitata Gorge and the Lake Clearwater and Lake Heron basins. Detailed identification of glacial and fluvioglacial landforms associated with the younger glacial advances is presented.

5. SUMMARY

Most of the important information relating to the glacial sequences is contained in the thesis maps. It will be recalled that the main aims were to present maps which reflected the general characteristics of the area, that presented the full range of data obtained, that were easily understandable and consistent with other workers. These requirements could not all be met using a single mapping approach, thus two sets of maps are presented. 1:50,000 scale lithostratigraphic maps provided a meaningful synthesis of the whole field area. Although lithostratigraphic principles could not be fully applied, the mapping of informal formations provided for easily recognisable units in a style consistent with the N.Z. Geological Survey mapping programme. 1:25,000 scale geomorphological maps allow for the detailed presentation of morphologies from critical areas.

CHAPTER 5

METHODS

1. INTRODUCTION

The basic objective of this thesis is to describe the geomorphology of the study area so as to define the sequence of glacial advances that has been partly responsible for shaping the landscape. The nature of the study area required the assembling and presentation of a large amount of data from a wide area. Thus the primary aim was to map the position and elevation of the glacial and fluvioglacial landforms and lithologies so as to construct lithostratigraphic and geomorphological maps. This involved the use of various source materials, field techniques and mapping methods.

2. WORK PROGRAMME

Preliminary mapping and compilation of field sheets were based on aerial photographs. During field work this preliminary mapping was checked and more detailed information obtained. Further air photo analysis and data collation identified the main problem areas, and subsequent field work was concentrated on these areas. Final maps were then drawn and field checked. This work was carried out from mid-1977 to mid-1980.

3. SOURCE MATERIALS

The main resource materials were Lands and Survey Department maps, aerial photographs, Soil Bureau and Geological Survey maps.

i) Topographic Maps.

Topographic maps used were the N.Z. Lands and Survey Department maps of the N.Z.M.S.1 series at a scale of 1:63,360. The most frequently used were sheets S/73 (Lake Heron), S/80 (Macauly), S/81 (Mt. Somers) and S/91 (Mt. Peel). Also referred to were S/72 (Godley), S/82 (Methven), S/90 (Lake Tekapo), S/92 (Ashburton), S/102 (Geraldine) and S/103 (Hinds). At the time of writing NZMS 260 (1:50,000) topographic maps were not available, however the main thesis maps have been plotted at this scale using the metric grid and sheet boundaries. The main N.Z.M.S. 260 maps covered on the thesis Maps 1-4 are J/35/36, K/36, with minor parts of I/35/36/37, J/37 and K/35/37 also included.

Grid references in the thesis are given using the metric NZMS 260 1000 m grid, with the NZMS 1, 1000 yd. grid references given second.

ii) Aerial Photographs.

The most important resource materials used were the aerial photographs obtained from the Lands and Survey Department. All of the area of the Rangitata and Ashburton catchments, from the main divide to the coast, is covered by aerial photos of varying scales. Those covering the central portions of the two catchments were most frequently referred to. They were:

3727/17-22	3732/9-16	
3728/6-22	3733/7-15	Flown 1964 at 25,000 ft.
3729/5-22	3734/14-21	Lens f: 114.41 mm
3730/5-22	3735/15-22	
3731/7-17	3736/19-28	
S73/8A-C	S81/1A-C	
S80/3A-C	S81/2A-C	
S80/5B-C	S81/4A-C	Flown 1972-74 at 25,000 ft.
S80/6A-C	S81/5A-B	Lens f: 88.3, 114.41 mm
S80/8A-C	S81/7C	
S80/8A-C	S81/8AB	

Other aerial photos referred to (covering the upper catchments and lower plains areas) were from runs 3495-8, 2507, 3697, 3224-6, SN5054/A-C, SN5204/G, 572/9, 573/7 and S90/2-3.

iii) Other Maps.

Reference was also made to N.Z. Geological Survey and N.Z. Soil Bureau Maps. These were:

N.Z.G.S. Maps: Sheet S17, Hokitika (Warren 1967)
Sheet S20, Mt. Cook (Gair 1968)
Sheet S21, Christchurch (Suggate 1973)

N.Z. Soil Bureau Maps to accompany Bulletin 14 (Kear *et al.* 1967).

iv) Previous Work.

Studies by other workers in this area were available. These were dealt with in Chapter 3.

4. FIELD TECHNIQUES

Field techniques used in the study were similar to those employed by other workers (see for example Gage 1958). Standard geological mapping techniques and equipment were employed. The basic objective in the field was to describe accurately, and identify, the various landforms and to establish morphological relationships. This information was supplemented where possible with data from exposures of the deposits.

Heights were obtained in the field using an aneroid barometer. Corrections for temporal pressure fluctuations were taken from a microbarograph sited at a trig station. Corrections were also made for variations in air temperature. Heights obtained in this manner are believed to be accurate within ±5 m.

5. AERIAL PHOTOGRAPH ANALYSIS

The mapping of an area of the size and shape of the Rangitata-Ashburton system would have been virtually impracticable without the use of vertical aerial photographs. They afford an unparalleled view of the landscape, allowing time saving reconnaissance mapping and identification of potential problem areas prior to field work. The high altitude photo coverage provided an overview of large parts of the field area and could be easily referred to in the field.

Preliminary identification of morphologies on aerial photographs was transferred to the NZMS 1 (1:63,360) topographical maps using a Zeiss Aero Sketchmaster. This is a second order plotting instrument that enables accurate planimetric projection of aerial photos onto base maps. At the scale used (approximately 1:60,000) the horizontal accuracy is approximately ±20 m. The method is best suited to areas of low or moderate relief and is unsuitable for high relief areas. In some of these areas cross profiles were constructed from the aerial photographs, and information obtained was then plotted, with reference to the contours, on the topographic maps.

The preliminary maps were traced onto ammo-permatrace overlay sheets. In this form the maps could be easily copied and corrected. This also allowed areas of particular interest, and problem sites, to be photographically enlarged to a suitable working scale.

The aerial photos were used in the subsequent mapping stages to check the corrections to the maps and to assist in correlation of the various sequences.

6. FINAL MAPS

The main thesis maps (Maps 1-4) are presented at a scale of 1:50,000. This was considered to be the most effective scale appropriate to the area, and degree of detail required. The 1:50,000 scale was achieved by photographically enlarging the 1:63,360 permatrace sheets. Additional checking of the scale was done using the NZMS 261 (1:50,000) Cadastral Maps as a base for the final compilation.

Where necessary, maps at different scales have been used. Map 8, of part of the Canterbury Plains, was drawn using parts of NZMS 18 Sheets 20 and 21 as a base. The larger scale, more detailed maps (Maps 5-7) are based on photographically enlarged portions of the 1:50,000 maps, with further data plotted using the Sketchmaster.

CHAPTER 6

CRITERIA FOR DIFFERENTIATING GLACIAL ADVANCES

1. INTRODUCTION

During the Late Pleistocene the study area was occupied by numerous glaciers, the largest being the Rangitata and a distributary lobe of the Rakaia Glacier. Other important glaciers included the Cameron, Ashburton and Potts Glaciers.

The sequences described here are rather complex. Previous New Zealand workers have dealt with single valley glaciers and their distributary lobes (e.g. Gage 1958, Soons 1963, Speight 1963) and adjacent valley glaciers with common meltwater outlets (McKellar 1960, 1973; Clayton 1968). However, this study is concerned with a much more complex series of glacial and meltwater systems (Table 1).

TABLE 1. Major glacial and meltwater systems in study area

Glacial System	Meltwater Outlet
Main Rangitata Glacier	Rangitata River
Rangitata Glacier distributary lobe	Mainly to Ashburton River. Some via Pudding Valley to Rangitata River.
Ashburton Glacier	Ashburton River
Cameron Glacier	Ashburton River
Rakaia Glacier distributary lobe	Ashburton River

2. NOMENCLATURE

The system of nomenclature used to map the deposits of the various ice bodies is similar to that of Suggate (1965, p. 8). During the early ice advances all the glaciers coalesced, thus the same terminology is used. During the later advances the various ice bodies were all separate, and two systems of nomenclature are used: one for the Rangitata glacier, its distributary lobe and the Potts glacier; and the other for the Ashburton, Cameron and Rakaia distributary lobe glaciers.

3. SEQUENCE OF ADVANCES

Five main Late Pleistocene glacial advances can be recognised. For the younger of these advances, when the glaciers were separate, the two groupings outlined above are referred to by the name of the largest ice body in each group. These are shown on Table 2.

TABLE 2. Glacial sequences in the Rangitata and Ashburton Valleys

	RANGITATA GLACIER		RAKAIA LOBE
Youngest ↑	Spider Lakes Advance Hakatere Advance		Lake Heron Advance Emily Advance
↓ Oldest		Trinity Advance Dogs Hill Advance Pyramid Advance	

Smaller Holocene glacial advances are also recognised. However they have formed only a minor part of this study.

Where they can be identified they are mapped in two sets: an early Holocene group with individual formation names, and a late Holocene or recent unnamed set closer to the termini of the present day glaciers.

4. THE GLACIAL SYSTEMS

The extent of the glaciers during the various advances (excluding the Pyramid Advance) is shown on Figure 6. The Rangitata glacier was the largest, flowing from over 120 cirques at the heads of the Havelock, Clyde and Lawrence valleys. The main glacier extended through the Mesopotamia basin to the area of the Rangitata Gorge. A large distributary lobe left the glacier near the Rangitata-Potts River junction and flowed into the Lake Clearwater basin. This will be referred to as the Clearwater lobe.

The other large ice body was a distributary lobe of the Rakaia glacier system. This ice tongue flowed up the Lake Stream valley into the Lake Heron basin where it was joined by the smaller Cameron Glacier.

Two smaller glaciers, the Potts and the Ashburton, occupied valleys between the Lake Clearwater and Lake Heron basins during the Pyramid and Dogs Hill Advances. Initially these glaciers joined the ice masses in the nearby intermontane basins, but during the younger ice advances they remained separate from these larger glaciers.

Numerous small glaciers occupied valleys in the foothill ranges. The largest of these were in the headwaters of Bush Stream and Forest Creek in the Two Thumb Range.

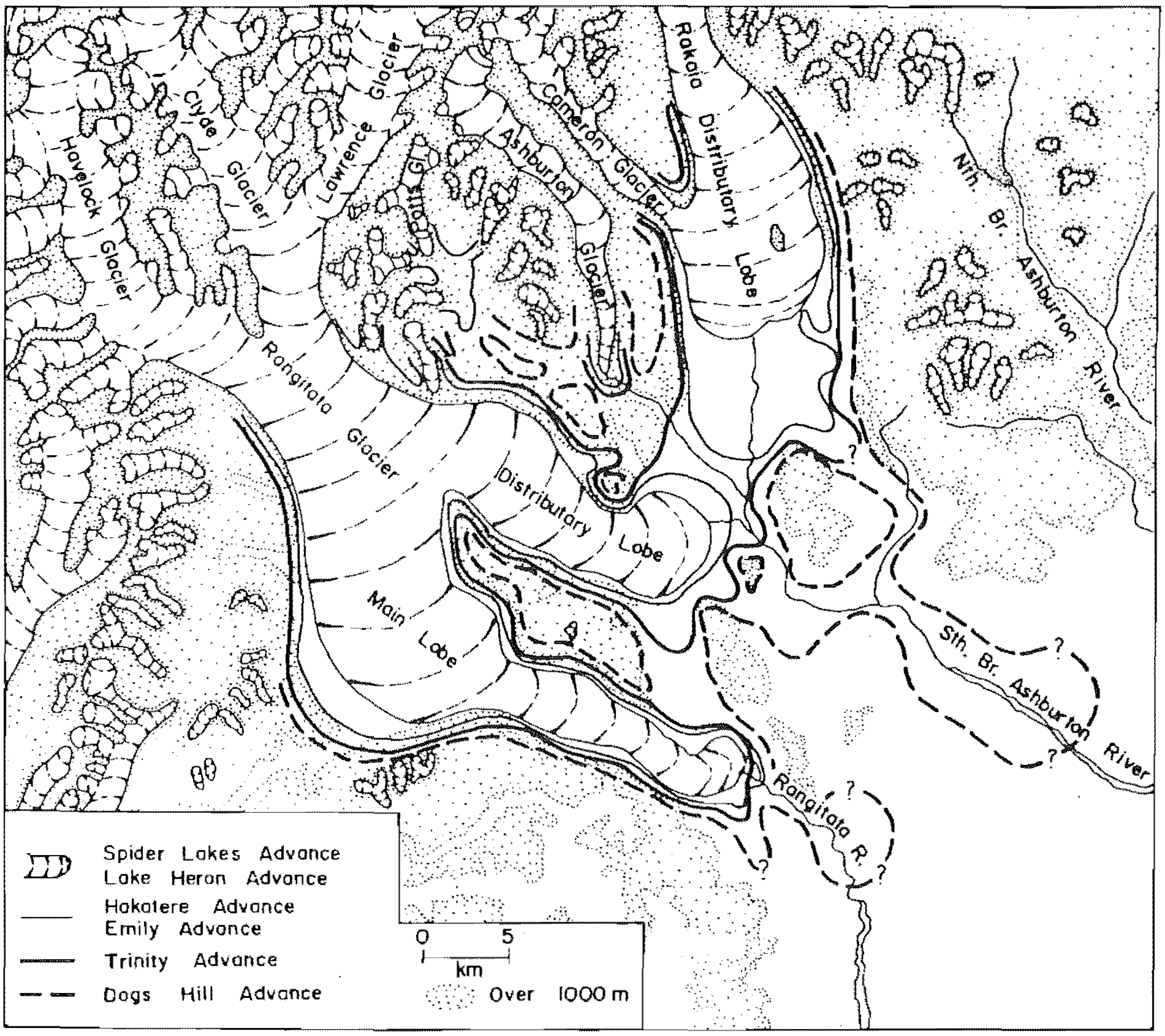


FIG. 6. : Limits of Late Pleistocene Glacial Advances in the Rangitata and Ashburton Valleys

Small valley and cirque glaciers were also present in the Ben McLeod, Sinclair, Harper, Red Hill, Palmer, Taylor and Mt. Somers Ranges.

The limits of all these glaciers during the earlier Pyramid and Dogs Hill Advances cannot be well defined. However it is clear that they coalesced and flowed across the foothill ranges onto the inner plains margin. Ice limits relating to the younger advances can be more clearly identified, and except for one period when the Rangitata and Rakaia distributary lobes just joined, the main glaciers remained separate and did not extend beyond the intermontane basins.

5. DISTINGUISHING BETWEEN THE ADVANCES

A variety of criteria have been used to differentiate the various advances. These are largely the morphological criteria used by Gage (1958) and most subsequent workers. In such previous studies emphasis was placed on the relative height differences between the moraines and outwash surfaces of the various advances. Commonly, advances were recognised on the basis of an outwash surface remnant that could be traced upvalley into a presumably contemporaneously formed moraine feature. However in this study area, although there are extensive areas of moraines and outwash surfaces, these can rarely be confidently correlated. The intermontane basins and foothill ranges contain large areas of moraine features and only minor outwash surface remnants, whereas the inner plains margin consists almost entirely of fluvial surfaces.

The gorge sections of the Rangitata and Ashburton Rivers, linking the intermontane basins with the inner plains margin areas, contain only scattered outwash surface remnants. In each case only one plain's surface can be confidently traced through the two gorges into a moraine. Thus the relative height differences between the moraines and outwash surfaces can not be used as in previous studies. Therefore the glacial sequences have been defined almost entirely on the basis of the morphological characteristics of the moraine suites in the intermontane basins and foothill ranges. The predominantly fluvial surfaces of the inner plains margin have been treated separately. Due to their distance from the moraine sequences they are not considered as true outwash surfaces, although their formation can be clearly related to periods of glacial advance. These fluvial surfaces are mapped as alluvial fan surfaces of the Ashburton-Rangitata River sector of the Canterbury Plains, and correlations with the inland glacial sequences are suggested.

6. DEFINING THE GLACIAL SEQUENCES

Differences in elevation, distribution and preservation of the moraines proved the most useful criteria for differentiating between the various advances. The nature of this evidence is shown in Table 3. The easiest to define are the youngest Spider Lakes/Lake Heron Advances. They have the smallest extent, occur at the lowest levels in the intermontane basins, and the morphologies retain most features of their original surface form. The older advances were progressively

TABLE 3. Criteria for differentiating glacial advances

Advance	Distribution	Occurrence	Level of identification	Preservation of surface form	Weathering of deposits
Spider Lakes/ Lake Heron	Extensive and continuous	Lower valley sides	Detailed identification of morphologies possible	Sharp	Slight weathering only (matrix)
Hakatere/Emily	Widespread and semi-continuous	Mid-lower valley sides and floors	Easy identification of morphologies possible	Slightly subdued	Slight weathering only (matrix)
Trinity	Discontinuous	Mid-high valley sides and some valley floors	Generalised identific- ation of morphologies possible	Mostly subdued	Slightly weathered (matrix)
Dogs Hill	Patchy	High valley sides and some ridge tops	Some generalised identification of morphologies possible	Very subdued	Weathered (matrix and clasts)
Pyramid	Patchy	Ridge tops and plateau surfaces	No morphologies identifiable	No preserved surface form	Well weathered (matrix and clasts)

larger glacial events, and their original surface form becomes increasingly modified. An example of a complete sequence of lateral glacial and associated features is shown in Figures 7 and 8.

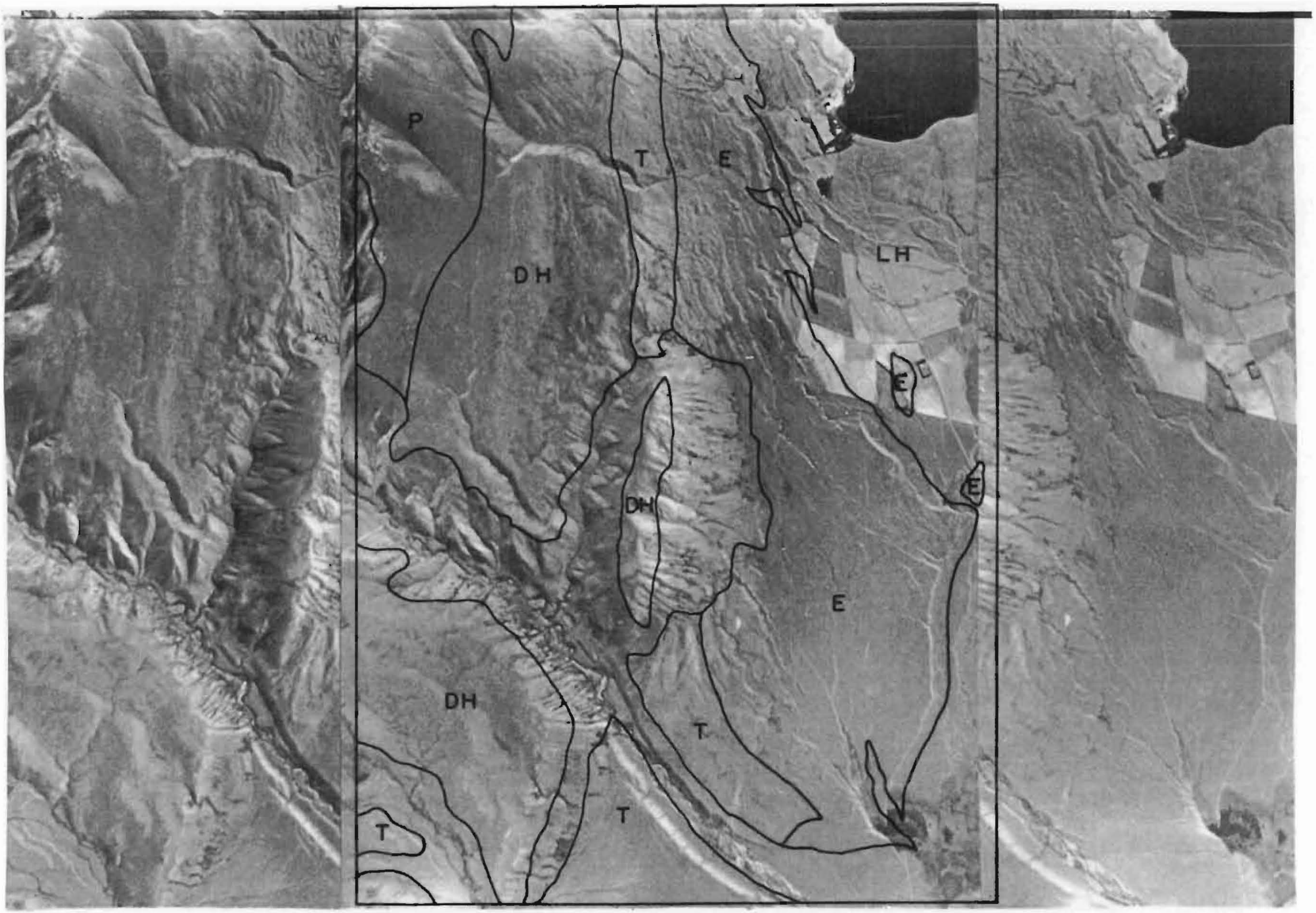
7. THE PLAINS SURFACES

The criteria used to differentiate the surfaces of the inner Canterbury Plains are the same as those used by Suggate (1958, 1963b). These include height above river level, weathering of the gravels, and the nature of the soil and loess cover.

Most of the surfaces are fluvial in origin. However ice did extend onto the inner plains margin during the earlier glacial periods, thus some moraine features have been identified.

The plains areas associated with the Ashburton and Rangitata Rivers are mapped as formations (Maps 3, 4, 8). Nomenclature used follows that of Oborn and Suggate (1959) and Gregg (1964), which was formalised by Suggate (1965) and has been subsequently used by Gair (1968) and Suggate (1973). This nomenclature was devised for the Waimakariri and Rakaia sectors of the Canterbury Plains to the north of the study area. As outlined above, correlation with the glacial sequence further inland is difficult. The correlations adopted in this study are shown in Table 4.

FIG. 7. Stereo triplet of part of the Lake Heron basin and foothill ranges. Part of Lake Heron in north-east corner. Ashburton River cuts across the south-west corner. (LH = Lake Heron Advance, E = Emily Advance, T = Trinity Advance, DH = Dogs Hill Advance, P = Pyramid Advance).



Photos: Lands & Survey Dept. S81/1/C; 2/A, B.

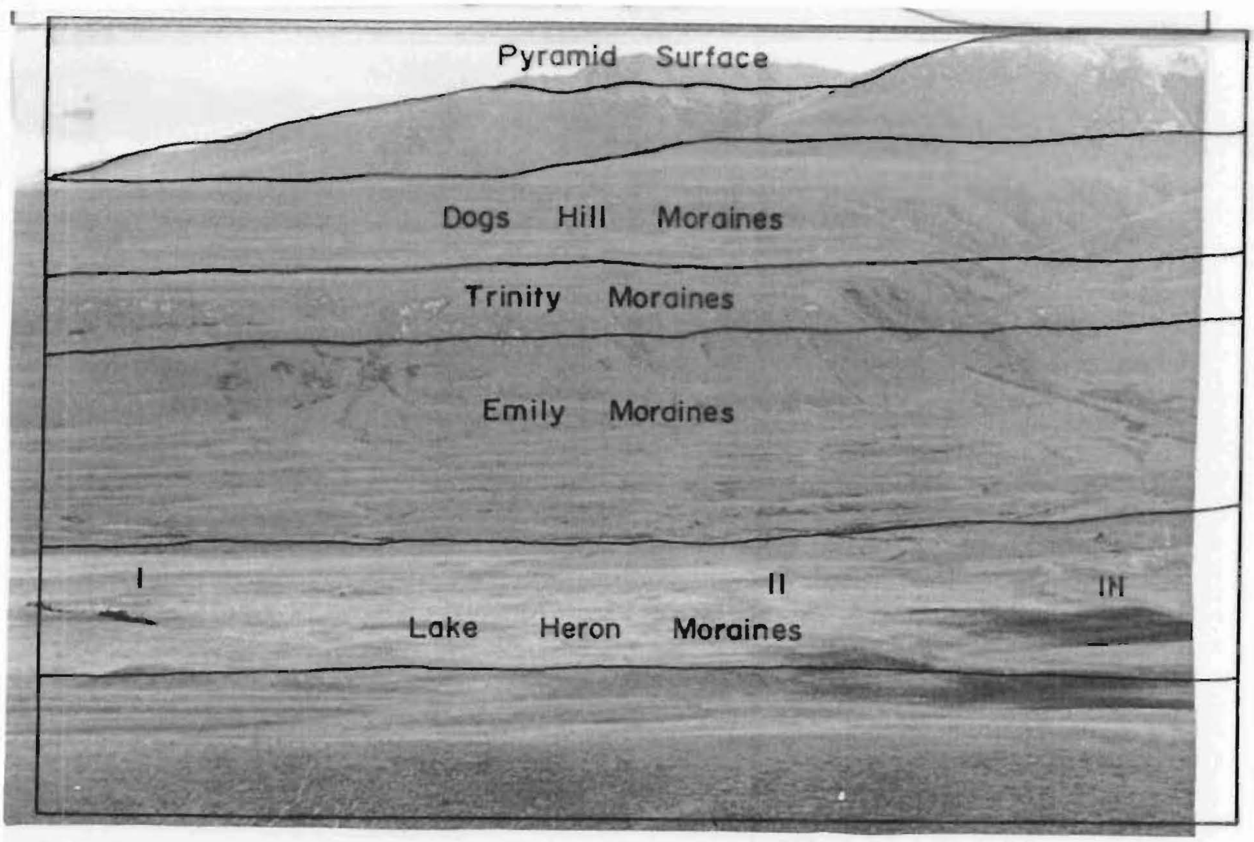


FIG. 8. View west of part of the Lake Heron basin and foothill ranges as shown in part of the northern section of Figure 7. Lake Heron Advance 1, 2 and 3 end moraines labelled in basin floor. Lateral moraines of older advances can be seen on the slopes behind.

TABLE 4. Correlation of Late Pleistocene formations mapped in study area

Intermontane Basin and Foothill Range Formations	Inner Plains Margin Formations
Spider Lakes/Lake Heron	St. Bernard
Hakatere/Emily	Burnham
Trinity	Windwhistle
Dogs Hill	Woodlands
Pyramid	Hororata

8. PRESENTATION OF MATERIAL

The basic data on the glacial sequences is contained in maps 1-7 and Figure 9. Maps 1-4 show the deposits of each advance, mapped as formations at a scale of 1:50,000, and cover the intermontane basins, foothill ranges and inner plains margin. Maps 5-7 show the geomorphology of the Lake Heron basin, Lake Clearwater basin, and the area at the head of the Rangitata Gorge at a scale of 1:25,000. Map 8, at a 1:250,000 scale, shows the geology of the Canterbury Plains between the Rakaia and Orari Rivers. Figure 9 depicts the height relationships between the major moraines, outwash and plains surfaces, and Figure 6 shows the ice limits of the various advances.

In Part Two the formations shown on maps 1-4 will be described. Part Three will deal with the three major glacial sequences mapped in detail on maps 5-7, and the Canterbury Plains area.

PART TWO: GLACIAL AND ASSOCIATED DEPOSITS AND LANDFORMS

CHAPTER 7

THE PYRAMID ADVANCE

1. INTRODUCTION

The deposits of the Pyramid Advance represent the oldest glacial advance or advances preserved in the study area. They are mapped as the Pyramid formation in the foot-hill ranges and the Hororata Formation along the inner plains margin. In practice these formations include all deposits higher than those of the more clearly definable Dogs Hill and Woodlands Formations (see Chapter 8). It is thus possible that deposits of more than one age are included.

2. PYRAMID AND HORORATA FORMATIONS

i) Pyramid Formation

a) Name and Distribution: The name Pyramid Formation is taken from Pyramid (Trig V, 1595 m, Map 1, J35/559492, S73/642666), a peak on the high level surface between the Cameron and Ashburton Rivers.

Deposits of this formation are scattered throughout the field area (Maps 1-3). The two most extensive areas lie between the Lake Heron basin and the Ashburton River (here called the Pyramid surface) and 20 km to the south between the Moorhouse Range and Ashburton River (here called the Inverary surface).

ii) Hororata Formation

a) Name and Distribution: The Hororata formation is formally defined by Suggate (1965, p. 17). It occurs in isolated patches along the inner margin of the plains (Maps 3, 8).

iii) Surface Form

Two groups of morphologies can be recognised: an inland set around the intermontane basins, including the Pyramid surface; and a set along the foothill ranges near the inner plains margin, characterised by the Inverary surface.

The Pyramid surface, and its correlatives on the Harper, Clent Hills and Dogs Ranges, occur as ridge top cappings on the ranges around the intermontane basins (see Fig. 10). These surfaces are well rounded, rolling and have been deeply dissected by small streams. They show signs of modification by periglacial processes, with active stone stripes being common on the Pyramid surface. This surface also has the most relief, ranging in height from 1250 m - 1660 m a.s.l. On other ridge tops the formation is less extensively preserved and most remnants range between 1220 m - 1370 m a.s.l.

The Inverary surface, and its correlatives in both the Pyramid and Hororata Formations, occur along the ranges near the inner plains margin. They form an extensive gently rolling plateau with some enclosed swampy depressions,

FIG. 10. View north-west across Dogs Range towards Red Mountain. Ashburton Valley in distance at right. Dissected remnants of Pyramid formation on ridge tops.

ranging in height from 640 m - 730 m a.s.l. Although much lower and less modified than the Pyramid surface, these surfaces have also been dissected. The North Branch of the Hinds River is incised 220 m below the general level of the Inverary surface, with 100 m of this cut through solid rock.

iv) Deposits

The Pyramid and Hororata formations are not well exposed. No exposures of the Pyramid surface and its correlatives was found. However Burrows (1975, *pers. comm.*)

reports strongly weathered till from near Pyramid, and in the Cameron Valley. Along the Dogs Range (Map 3, J36/523376, S81/600540) exposures of solid greywacke beneath the Pyramid formation suggest a thickness in excess of 150 m.

Two clear exposures of the Inverary surface were seen. At grid ref. Map 3, J36/698254, S81/790402, on the northern bank of Blondin Stream, the following section is exposed:

3 m poorly sorted, subrounded, yellow/brown greywacke gravels up to 0.75 m across in a weathered sandy matrix. Interpreted as either proximal outwash or till.

The gravels are somewhat compacted and poorly bedded. This exposure occurs approximately 120 m below the general level of the Inverary surface.

At grid ref. Map 3, J36/708247, S81/800397, in a track cutting on the south side of the Blondin Creek Valley the following section is exposed (see Fig 11):

3 m poorly sorted, sub-angular and subrounded reddish-yellow/brown greywacke gravels up to 0.75 m across in a weathered coarse sand and clay matrix. Interpreted as till.

The gravels are slightly compacted and break easily with a hammer blow. The exposure occurs 15 m below the level of the Inverary surface.

FIG. 11. Pyramid formation till exposure Blondin Creek Valley.

v) Interpretation

Interpretation of the morphologies is problematic. They do not bear any obvious relationship with the present drainage system, and no traces of the original surface form could be identified. However, large sub-angular greywacke boulders up to 3 m across are common on these surfaces, which does suggest a glacial origin. This interpretation is supported by the exposures described above. Thus the Pyramid and Hororata formations have been mapped as till. The various surfaces are considered to be the degraded remnants of moraine features.

vi) Ice Extent

At the maximum of the Pyramid advance ice must have filled the intermontane basins and flowed across the foothill ranges onto the inner plains margin. Ice levels exceeded 1580 m a.s.l. west of Lake Heron, reached 1310 m a.s.l. on the Harper and Clent Hills Ranges, and issued across the foothill ranges onto the plains at about 800 m a.s.l.

The combined Rakaia and Clearwater lobe glaciers diverged into three lobes as they flowed out of the intermontane basins. One lobe passed to the north of the Clent Hills Range down the valley of the Stour River. U-shaped channels cut in this valley on the lower slopes of the range at 830 m a.s.l. can be seen at grid refs. Map 3, J36/704319, S81/797477 and J36/717323, S81/812480 (Speight 1938, Fig. 6). The other two lobes passed to the south of the Clent Hills, down the Ashburton and Trinity Valleys. A u-shaped channel 830 m a.s.l. can also be seen on Trinity Hill (Map 3, J36/634295, S81/720450). These three lobes recombined near the junction of the Stour and Ashburton Rivers and flowed out past Mt. Somers. The glacier would have been in excess of 15 km wide as it left the foothill ranges. There is however no evidence indicating its extent onto the plains.

The main Rangitata glacier split into two lobes as it flowed across the foothill ranges. The northern lobe occupied the valley in which the present Rangitata gorge is cut, while 2 km to the south the other lobe passed through the Whiterock depression. In this case also there is no evidence as to the eastern limit of the lobe.

vii) Age

The weathering, surface deformation and stratigraphic setting of the Pyramid and Hororata formations indicate that they are the oldest late Pleistocene deposits preserved in the study area, and are considerably older than the other formations. The deposits were clearly formed after the major features of the landscape had evolved and they show no obvious signs of tectonic deformation, although the Kaikoura orogenic movements are continuing at the same rate as any earlier stage (Suggate 1978).

It is possible that the deposits of these two formations represent more than one glacial episode. The Inverary surface is 600 m lower and rather less dissected than the Pyramid surface. This may simply reflect the harsher conditions that the Pyramid surface has been subjected to in its more mountainous setting, but the lower Inverary surface could be rather younger. The possibility that the Hororata Formation, as mapped by Gregg (1964), may include deposits of more than one glaciation is noted by Suggate (1965, p. 17).

CHAPTER 8

THE DOGS HILL ADVANCE

1. INTRODUCTION

The deposits of the Dogs Hill advances are mapped as the Dogs Hill formation in the intermontane basins and foothill ranges, and the Woodlands Formation along the inner plains margin. Till, outwash and alluvial fan deposit members are recognised.

2. DOGS HILL AND WOODLANDS FORMATIONS

i) Dogs Hill Formation

a) Name and Distribution. The formation is named from Dogs Hill (Trig H, 1049 m, Map 3, J36/574347, S81/656519) a peak on the undulating surface between the Ashburton River and Paddle Hill Creek.

Deposits are preserved in isolated patches on the foothill ranges, the two largest areas occurring to the west of the Lake Heron Depression (Maps 1-3).

ii) Woodlands Formation

a) Name and Distribution. The Woodlands Formation is formally described by Suggate (1965, p. 17). It occurs extensively around Mt. Somers township, between the Peter Range and Gawler Downs, and on the South Bank of the

Rangitata River (Maps 3, 8).

iii) Surface Form

a) Till Members. Morainic topography on the till members of both formations is very subdued. In some places specific forms can be recognised. On the ridge between the Lake Heron depression and the Ashburton River, a 3 km long flat topped ridge 440 m wide and 35 m high can be seen (Fig. 12) (grid ref. Map 1, J35/574426, S81/656595). It is interpreted as a lateral moraine ridge. Inside this is a gently undulating area containing numerous enclosed swampy hollows, which is interpreted as ablation moraine.

FIG. 12. Dogs Hill formation on foothill ranges at the southern end of the Lake Heron basin. Subdued lateral moraine ridge arrowed.

On the outer side of the ridge, and about 150 m higher, remnants of a slightly older lateral moraine are preserved.

On the Harper Range at grid ref. Map 2, J36/490295, S81/560455 similar morphologies are preserved. Two lateral moraine ridges are separated by 95 m altitude and an area of gently rolling swampy ablation moraine. The lower ridge is 220 m wide and 25 m high.

A well formed lateral moraine can also be seen on High Terrace (Map 2, J36/365195, S80/425350), however on most other occurrences of the till member the morainic topography is not identifiable. On the foothill ranges around the intermontane basins, the Dogs Hill formation commonly occurs between 1300 m - 1100 m a.s.l., or 430-630 m above the floors of the basins. Further east through the Ashburton Gorge the formation does not exceed 610 m a.s.l.

Large areas of Woodlands Formation till are mapped in the area to the north of Mt. Somers township. Here the morainic topography is very subdued, although greywacke boulders can be seen on these surfaces particularly south from Mt. Somers station. These surfaces are gently undulating and contain swampy hollows. The low relief of this member is probably due to the occurrence of at least two sheets of loess on the surfaces. A 7.7 m loess section can be seen in a road-cutting through the Woodlands Formation at grid ref. Map 3, K36/815252, S81/919397. These surfaces occur between 370 m - 520 m a.s.l., however at any one place total relief rarely exceeds 30 m.

b) Outwash Members. Outwash surface remnants associated with the Dogs Hill advance are restricted to the Mt. Somers area and are mapped as Woodlands Formation. The most extensive occurrence is between the Peter Range and Gawler Downs. These surfaces are confined between the North and South Branches of the Hinds River and slope southwards from 495 m to 415 m a.s.l. They have been dissected by the Gawler Stream and its tributaries which are incised 30 m below the level of the outwash surface remnant.

Other lower outwash surface remnants can be seen near the Ashburton River (Map 3). These isolated remnants occur up to 60 m below the general level of the till member and are thus presumably slightly younger than the till preserved in this area.

c) Alluvial Fan Members. The alluvial fan member of the Woodlands Formation is relatively widespread along the inner plains margin. The highest surface of the multi-storeyed fans beneath Mt. Somers have been mapped as this formation, as are the high level fans extending from Raules Gully on the south bank of the Rangitata River. There are two prominent levels in these fans, the upper being approximately 15 m above the lower.

iv) Deposits

Both formations are very poorly exposed. However examples of the deposits of each member have been located.

a) Till Members. In a track cutting at grid ref. Map 3, J36/632202, S81/717347 on the lower flanks of the Moorhouse Range the following section is exposed:

2 m non-bedded, sub-angular, yellow-brown greywacke gravels up to 40 cm across, in a coarse sand and clay matrix. Interpreted as till.

The base and top are not seen, however the exposure occurs 30 m below a surface mapped as the Dogs Hill formation alluvial fan member. An exposure of till in a similar stratigraphic setting can be seen in Haast Stream Valley. This is described below in the alluvial fan section (p. 58).

Woodlands Formation till is exposed in a trackcutting near the downstream end of the Rangitata Gorge. At grid ref. Map 3, J36/668140, S91/757282 the following section appears (Fig. 13):

2.5 m non-bedded, very poorly sorted, sub-angular and subrounded yellow-brown greywacke gravels up to 0.5 m across in a coarse sand - silt matrix. Interpreted as till.

FIG. 13. Woodlands Formation till near downstream end of the Rangitata Gorge.

The top of the deposit is not seen, but at least 2 m of loess can be seen to overlie the till in exposures nearby.

b) Outwash Deposit Members. No exposures of the Dogs Hill formation outwash member were seen, and only one exposure of this member of the Woodlands Formation was located. At grid ref. Map 3, J36/743265, S81/840415 the following section appears in an abandoned silica sand mine:-

3.5 m bedded, rounded, yellow-brown gravels up to 25 cm across in a sandy matrix. The lower 0.5 m iron stained.

0.3 m yellow-brown medium sand.

3 m non-bedded sub-rounded, red-brown gravels up to 0.75 m in cobble and sand matrix.

The upper gravel unit contains some greywacke, but consists mostly of locally derived volcanic rocks. It is interpreted as outwash. The 30 cm of sand is essentially the same as nearby exposures of silica sand and is apparently reworked from these other deposits. The lower gravel unit is composed of volcanic rocks and contains no greywacke. It is probably a slope deposit from Mt. Somers, the lower slopes of which are 0.5 km to the north of this exposure.

c) Alluvial Fan Deposit Member. In a stream bank at grid ref. Map J36/645348, S81/734508 in the Haast Stream valley the following section is exposed (Fig. 14):

3 m non-bedded, subrounded, yellow-brown greywacke gravels up to 30 cm across in coarse sand-clay matrix. Interpreted as till.

9 m horizontally bedded, subrounded, yellow-brown greywacke gravels up to 10 cm across, interbedded with coarse sand units up to 30 cm thick.

1 m horizontally bedded, coarse and fine sand units with 7 cm peat lens 60 cm from base.

5 m horizontally bedded, subrounded, yellow-brown greywacke gravels up to 10 cm across in medium sand matrix.

Photo: R.M. Kirk

FIG. 14. Dogs Hill Formation alluvial fan deposits. Peat layer at level of figure.

The lower three units are interpreted as alluvial fan deposits of the Dogs Hill formation. The presence of till in these deposits suggests that the alluvial fan was built out against ice. The pollen flora in the peat is described in Appendix 1.

An exposure of the Woodlands Formation alluvial fan member can be seen in Middle Stream (Map 3, J36/675107, S91/765242):

20 m bedded, subrounded, yellow-brown greywacke gravels up to 10 cm across, interbedded with bands of brown fine sand and silt.
1.5 m grey clay.
1.5 m brown fine sand and silt with 0.5 m lenses of gravels up to 5 cm across.
3 m poorly bedded, sub-angular, yellow-brown greywacke gravels up to 50 cm across in coarse sand matrix.

v) Ice Extent

The probable ice extent during the Dogs Hill advance is shown in Figure 6. Ice completely filled the intermontane basins to about 1280 m a.s.l. The Ashburton Glacier flowed into the Lake Heron basin via its present valley and also down the Paddle Hill Creek Valley. The Potts glacier joined the Clearwater lobe in the Lake Clearwater basin and also flowed down the valley of Boundary Stream to join the Ashburton Glacier.

The combined Rakaia and Clearwater lobe glaciers flowed across the foothill ranges using the same channels as did the Pyramid Advance. However the ice stream was only 2.5 km wide and 580 m a.s.l. as it flowed down the Ashburton Valley onto the inner plains. The main Rangitata Glacier flowed through the gorge, issuing onto the plains at about 490 m a.s.l.

A distributary lobe flowed in the Whiterock depression to the south of the gorge, probably as far as Boundary Creek.

The two levels of lateral moraines on the Harper Range, and along the west of the Lake Clearwater depression, suggest that there were at least two advances during the Dogs Hill Advance. However no clear terminal positions can be determined on the inner plains margin. During the earlier advance the combined Rakaia and Clearwater lobe glaciers flowing down the Ashburton Valley reached at least as far as the subdued moraines preserved 3 km east of Mt. Somers township (Map 3, K36/840220, S81/944365). The glacier probably formed a large piedmont lobe nearly 10 km across extending from the base of Stevenson Hill in the north (Map 3, K36/809274, S81/913423) to the north end of Gawler Downs (Map 3, J36/789175, S81/886315) in the south. The high level alluvial fans on Mt. Somers were probably built up to the side of this ice body, while to the south ice appears to have overtopped the ridge to the south of the Ashburton River and extended as far as the North Branch of the Hinds River. Meltwater flowing south from here formed the now dissected outwash surface between the Gawler Downs and Peter Range. The younger ice advance did not extend onto the plains. The Woodlands Formation outwash member preserved in the Ashburton Valley is below the level of moraines around Mt. Somers (Fig. 9) and can be traced up valley as far as Woolmer Hill (J36/712269, S81/807421). Thus the ice limit was presumably in the region of the junction of the Stour and Ashburton Rivers at about 550 m a.s.l.

The ice limits of the Rangitata Glacier cannot be determined. However the till described above (p. 57) from the downstream end of the gorge indicates that ice did at least extend some way onto the plains. The high level alluvial fans preserved at Raules Gully, Middle and Chapman's Streams contain two distinct levels, indicating two periods of aggradation which may be correlated with the two phases of ice advance identified in the Ashburton Valley.

vi) Age Relationships

The Dogs Hill and Woodlands formations are clearly younger than the deposits of the Pyramid Advance. The morphologies occur at lower levels, and the deposits, while exhibiting a similar colour of weathering, contain gravels that are weathered right through. Individual clasts are difficult to break with a hammer. Thus it is considered that the two sets of advances are separated by at least one interglacial interval. The Woodlands and Dogs Hill formations can be clearly separated from all younger formations by the nature of both the deposits and morphologies. Thus they are considered to be separated from these latter by an interglacial interval as well.

CHAPTER 9

TRINITY ADVANCE

1. INTRODUCTION

The deposits of the Trinity advance are confined to the intermontane basins and foothill ranges. They are mapped as the Trinity formation. On the inner margin of the Canterbury Plains deposits presumed to have been laid down contemporaneously are mapped as the Windwhistle Formation. In the upper Rakaia Valley the correlative of the Trinity formation is mapped as the Tui Creek formation

2. TRINITY FORMATION

i) Name and Distribution.

The formation is named from Trinity Valley (Map 3, J36/615285, S81/700440). Deposits are discontinuously preserved around the periphery of the intermontane basins and on the lower slopes of the foothill ranges (Maps 1-3). Till, outwash, meltwater channel and alluvial fan deposit members are mapped.

ii) Surface Form.

a. Till Member. Moraines of various kinds can be recognised, although they have all been partially subdued. Lateral moraines of this advance can be seen around the Lake Heron, Lake Clearwater and Mesopotamia basins. A prominent pair of ridges can be traced along the western side of the Lake Heron depression for 3.5 km south from near the Cameron River. The ridges are up to 20 m high, 30 m across and are 65 m apart. A continuation of them can be seen where the Ashburton River enters the basin. They slope southwards and appear to be coeval with a similar set of lateral moraines that can be traced north around the flanks of Mt. Guy. These moraines indicate that the Clearwater and Rakaia lobe glaciers coalesced during the Trinity Advance at about 830 m a.s.l. At the head of Whiskey Stream on the Harper Range (Map 2, J36/480303, S81/552462) a suite of Trinity lateral moraines is preserved. Two ridges 65 m apart are visible, the inner ridge being up to 60 m high and the outer 35 m high. The moraine ridges are symmetrical, having 19^{o} inner and outer slopes, and the crests show slight rounding of form. Less well preserved lateral moraine suites can be seen on the lower slopes of the Dogs and Clent Hills Ranges and on the Low Hills near Whiterock station in the Rangitata Valley.

Subdued end moraine ridges are mapped at three localities. In Pudding Valley at Map 3, J36/590250, S81/675405 a subdued end moraine ridge 1.3 km long and 300 m across rises 15 m above its outwash surface. The end moraine complex in Trinity Valley (Map 3, J36/615285, S81/700438) is even more subdued, rising only 3 m above its outwash surface. A small remnant of end moraine is also preserved between the junction of Potato Stream and the Ashburton River (Map 3, J36/628327, S81/716485). The crest is 65 m above river level and 30 m above the small remnant of outwash surface that leads down valley from it.

A large area of Trinity till is mapped at the southern end of the Lake Heron basin to the west of Maori Lakes. The surface here slopes northwards from 750 m - 670 m a.s.l. and is gently undulating with several swampy enclosed hollows. It is interpreted as ablation moraine, formed by the Rakaia distributary lobe glacier. It has been vertically offset approximately 25 m by the Lake Heron Fault (see Appendix 2).

b. Outwash Deposit Member. Occurrences of this member are largely confined to the valleys draining through the foothill ranges away from the intermontane basins. The most extensive area can be seen in Pudding Valley. The outwash surfaces here occupy almost the entire width of the valley (2.5 km) and extend for 4.5 km from an end moraine ridge (p. 64). Some surface channelling has been preserved. Three distinct levels of surfaces can be identified. The higher surface is preserved around Trig B (Map 3, J36/584238, S81/665388). It rises 17 m above the main Pudding Valley surface which slopes from 685 m - 600 m a.s.l. towards the Rangitata Valley. Scattered remnants of a surface 8 m lower can be seen on the north bank of Pudding Valley Stream (Map 3, J36/592210, S81/673360) and along the eastern side of the valley at the base of the Moorhouse Range.

The main terrace preserved through the Ashburton Gorge has been mapped as Trinity outwash. It can be traced up the Ashburton and Trinity Valleys to the end moraine remnants described above (p. 64). In most cases a single outwash surface level is preserved, however at the head of the Ashburton Gorge, near the presumed Trinity Advance ice limit, three levels can be seen. The lower surface, 38 m above river

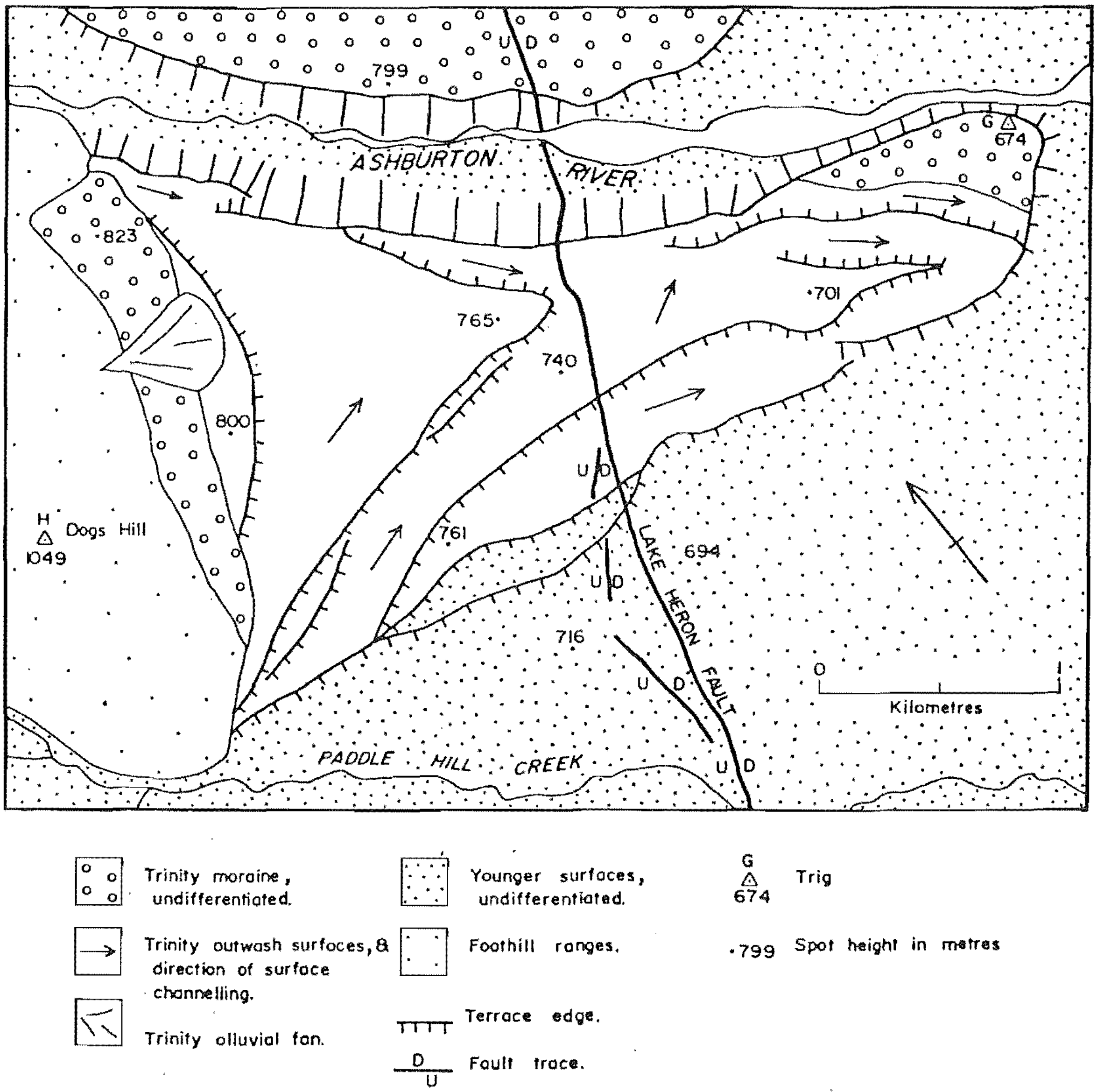


FIG. 15. Trinity Advance outwash surfaces at the southern end of the Lake Heron basin.

level, can be traced for 300 m south-east from the moraine near Potato Stream. Two other terraces 50 m and 55 m above river level are visible here. These are related to the outwash surface remnants further down valley, however small alluvial fans from the Clent Hills have obscured the exact nature of the height relationships.

An area of Trinity outwash is mapped at the southern end of the Lake Heron basin between the Ashburton River and Paddle Hill Creek. These surfaces are shown in Figures 15 and 16.

FIG. 16. View west of Trinity outwash surfaces at the southern end of the Lake Heron basin. Ashburton River, centre, flows from right to left. Trinity lateral moraines arrowed.

Four prominent terrace levels can be seen, ranging in height from 800 m - 650 m a.s.l. The surfaces are clearly channelled and have been vertically offset approximately 25 m by the Lake Heron Fault (see Appendix 2). They are interpreted as having been formed between the Clearwater and Rakaia lobe after they had separated. Meltwater flowing from behind Mt. Guy down the Paddle Hill Stream Valley passed around in front of the retreating Clearwater lobe. Each terrace level marks a successive stage in the retreat of this ice front. Near the Ashburton River small terraces, meltwater channels and moraine features can be related to the Ashburton River flowing around in front of the Rakaia lobe glacier. Channels are preserved between 1070 m - 975 m a.s.l. in association with some small areas of lateral moraine. The channels, similar to those described by Soons (1964) in the Rakaia Valley, were formed marginally, against the side of the main Rangitata glacier. They are approximately 25 km upvalley from, and 520 m above the presumed terminal position of the Trinity advance.

d) Alluvial Fan Deposits Member. Alluvial fans that grade onto Trinity outwash surfaces and show no signs of more recent activity are included in this member. They are commonly truncated, form the upper levels of multi-storeyed fans, and occur in association with the outwash surface remnants described above.

iii) Deposits

Very few exposures of this formation were seen, with two of the members not being exposed at all.

a) <u>Till Member</u>. To the west of Maori Lakes, in the Ashburton Valley, deposits beneath the Trinity ablation moraine surface can be seen. The two exposures are not clear as slope wash has obscured much of the detail. At grid ref. Map 3, J36/598357, S81/683519 the following section is exposed:

1.5 m loess and soil.
7 m non-bedded, subrounded, slightly weathered greywacke gravels up to 30 across in fine sand and silt matrix. Interpreted as till.

Two hundred metres upvalley the following exposure occurs from 15 m below the top of the river bank:

8 m horizontally bedded, rounded, slightly weathered greywacke gravels up to 30 cm across, grading into
25 m horizontally bedded, rounded, yellow-grey greywacke gravels up to 20 cm across.

The gravels in this exposure, which is stratigraphically 20 m below the base of the previous exposure, are interpreted as proximal outwash. There appears to be no erosional break between the two units, thus the lower weathered set is considered to represent Dogs Hill Formation deposits that were reworked during the early phases of the Trinity advance.

b) <u>Outwash Member</u>. The lower Trinity outwash surface in Pudding Valley is exposed in the side of a small gully as follows (Map 3, J36/597209, S81/677358):

0.5 m loess and soil.
2.5 m horizontally bedded, rounded greywacke gravels up to 30 cm across in a sandy matrix.

7 m horizontally bedded, subrounded, yellow-grey greywacke gravels up to 20 cm across, in a sandy matrix.

1.5 m horizontally bedded, brown, medium-coarse sand.

10 m+ poorly bedded, subrounded, yellow-brown greywacke gravels up to 20 cm across, in a medium-coarse sand matrix.

Slopewash has obscured the nature of the contacts between the units. The lowermost weathered gravels probably represent Dogs Hill Formation deposits. Interpretation of the overlying sand unit is problematic. It may have been deposited during either the Dogs Hill or Trinity Advances, or may be related to sedimentation between these two advances. The upper gravel units are interpreted as outwash deposits of the Trinity formation. The lower of these presumably relates to an earlier phase of the Trinity Advance that reworked older weathered deposits, while the upper unit was deposited at a slightly later stage and consists of more freshly eroded material.

iv) Ice Extent

The ice extent during the Trinity Advance is shown in Figure 6. Ice filled the intermontane basins to a level of 975 m a.s.l. The Clearwater and Rakaia lobes coalesced in the area between Paddle Hill Creek and the Ashburton River. Small lobes of ice, terminating at about 670 m a.s.l., extended into the Pudding, Trinity, Ashburton and Stour valleys that drain away from the intermontane basins.

In the main Rangitata Valley the glacier reached to the area at the head of the gorge. No terminal moraines of this advance are preserved in the main valley. Drainage from

Pudding Valley 4 km up valley from the gorge does not appear to have been obstructed, being able to pass in front of the glacier and flow down the present gorge. Thus Trinity ice probably did not reach into the gorge, and ended as a broad front extending from the lateral moraines on Low Hills (762 m) across the Rangitata Valley to moraines above Whiterock Station. A small lobe of ice pushed 3 km into the Whiterock depression and terminated at about 565 m a.s.l. During the Trinity advance the Ashburton and Potts Glaciers were confined to the foothill ranges. The Ashburton Glacier terminated at 885 m a.s.l., 3.75 km east of the Lake Heron basin.

The double lateral moraine ridges in the intermontane basins, and three outwash surface remnants in the Pudding and Ashburton Valleys, indicate that there were several major fluctuations of the ice front during this advance.

v) Age

The much smaller ice extent and lesser dissection of the Trinity landforms indicate that this advance is younger than the preceding Dogs Hill advance. Trinity deposits are much less weathered than older gravels, and the presence of reworked Dogs Hill material suggests a non-glacial interval separated these two advances. Thus the period between the Dogs Hill and Trinity advances is considered to have been a full interglacial.

3. WINDWHISTLE FORMATION

i) Name and Distribution

The Windwhistle Formation is formally described by Suggate (1965, p. 17). It is confined to the inner plains area, occurring most extensively on the north banks of the Rangitata and Ashburton Rivers (Maps 3, 4). A single alluvium member is mapped.

ii) Surface Form

On the north bank of the Rangitata River the highest surface, 90 m above the river, is mapped as the Windwhistle Formation. It can be traced from the downstream end of the gorge at 472 m a.s.l. 13 km south where it is overtopped by the younger Burnham Formation at about 315 m a.s.l. The surface slopes to the south-east, away from the river. Surface channelling can also be seen aligned in this direction. A small remnant of this surface is also mapped near the Peel Forest settlement.

On the north bank of the Ashburton River the Windwhistle Formation can be traced from near the junction with the Stour River at 510 m a.s.l. for 24 km to the junction of the Ashburton River and Bowyers Stream at 262 m a.s.l. In this distance it progressively declines from 30 m - 8 m above river level. South-east from Mt. Somers township the surface slopes eastwards, away from the river, and some surface channelling can be identified.

iii) Deposits

Two exposures of Windwhistle Formation deposits are visible near the Ashburton River. In a gravel pit at the junction of Foxs Road and Provincial State Highway 72 (Map 3, J36/828214, S81/931356) the following section is exposed:

0.5 m	loess and soil.
3 m	poorly bedded, rounded greywacke gravels up to 30 cm across in a coarse sand matrix.

These gravels show some slight weathering and are interpreted as alluvium. Near the Inverary Station road bridge over the Ashburton River (Map 3, J36/727262, S81/822410) the following section appears beneath the surface of the Windwhistle Formation (Fig. 17):

0.75 m	loess and soil.
2.5 m	horizontally bedded, rounded greywacke gravels up to 30 cm across, grading into
3 m	horizontally bedded, rounded, pale yellow-grey greywacke gravels up to 20 cm across.

The upper gravel unit is distinctly less weathered than the lower, however there is no obvious erosional break between them. Thus the lower gravels are interpreted as Windwhistle Formation alluvium that was reworked from an older weathered deposit.

FIG. 17. Windwhistle Formation alluvium near Inverary Station road bridge. Colour change in gravels arrowed. Darker gravels at top are water saturated. Height of terrace approximately 15 m.

iv) Interpretation and Age

The Windwhistle Formation represents the remnants of two large alluvial fans deposited by the Rangitata and Ashburton rivers. These fans probably coalesced along the line of the present Hinds River. The surface slope of both fans is approximately 10 m/km. The Windwhistle Formation can be traced up the Ashburton River as far as the Stour River where it is at the same height as the Trinity formation outwash member. Thus these two formations are considered to have been deposited contemporaneously.

The surfaces mapped in this formation are scattered over a wide area. They can be correlated on the basis of their relationships to older and younger formations. They are the next highest surfaces above the Burnham Formation, and the deposits are slightly more weathered than these younger gravels. The Windwhistle Formation is clearly younger than the Woodlands Formation as it occurs at lower levels, the deposits are distinctly less weathered, the surfaces retain much of their original form and are overlain by only one thin loess sheet (see Fig. 17).

CHAPTER 10

THE HAKATERE AND EMILY ADVANCES

1. INTRODUCTION

The deposits of the Hakatere Advances of the Rangitata glacier are mapped as the Hakatere formation. The deposits of the Emily Advances of the Rakaia distributary lobe and Ashburton Glaciers are mapped as the Emily formation. On the inner margin of the Canterbury Plains, deposits considered to be contemporaneous are mapped as the Burnham Formation. Correlatives of these formations in the upper Rakaia Valley are mapped as the Bayfield formation.

2. HAKATERE FORMATION

i) Name and Distribution

The formation is named from Hakatere Station (Map 3, J36/623309, S81/708465). Deposits are preserved around the margins and at the eastern end of the Lake Clearwater basin. They can also be seen in the main Rangitata Valley near the upstream end of the gorge and along the western side of the Mesopotamia basin (Maps 1-3).

Five members of the Hakatere formation are mapped: till, outwash, meltwater channel, alluvial fan, and landslide deposits.

ii) Surface Form

The surface form of these deposits in the Lake Clearwater basin, and at the head of the Rangitata Gorge, is described and mapped in detail in Chapters 14 and 15 and Maps 5 and 6. The following section concentrates on those areas not covered in these later chapters.

a) Till Member. A variety of moraine types can be recognised, most showing only slight defacement of their original surface form.

Small remnants of Hakatere Advance end moraines of the Rangitata glacier main lobe are preserved near Whiterock Station and below Low Hills (see Map 5). End moraines of the Clearwater lobe can be seen at the heads of the Pudding and Trinity Valleys and to the east of Mt. Guy (see Map 6). In this latter area six individual ridges are preserved.

Lateral moraines of this advance are more widespread than the end moraines, occurring around the margin of the Lake Clearwater basin (Map 6), in the main valley on the Low Hills (Map 5) and on the western side of the Mesopotamia Basin. Here, between Bush and Scour Streams a suite of lateral moraine ridges is preserved. At least three ridges up to 30 m across and 8 m high can be seen between 1035 m - 885 m a.s.l. In this basin other areas of Hakatere till are mapped down to 700 m a.s.l. The surface form consists of gently undulating topography containing numerous swampy hollows interpreted as ablation moraine. Some areas are extensively kettled (Map 2, J36/393213, S80/455365).

Hakatere till is mapped in the upper reaches of Bush Stream (Map 2, I36/293184 S80/345335, I36/288216 S80/340370).

The hummocky topography contains no obvious ridge forms and is interpreted as ablation moraine. An area of Hakatere till is also mapped in a small intermontane basin in the Potts Valley (Map 1, J35/462458, S72/535632). Low lateral moraine ridges around the eastern margin of this basin are flanked by small remnants of an ablation moraine surface.

b) Outwash Deposit Member. Occurrences of this member are mainly confined to the intermontane basins, although isolated remnants are preserved in the valleys that drain away from them.

In the Rangitata Valley at the head of the gorge, four outwash surface remnants, ranging in height from 535 m - 475 m a.s.l., can be seen (Map 5, Chapter 14). Hakatere outwash surfaces are also preserved at the heads of the Pudding and Trinity Valleys (Map 6). In most cases these surfaces can be traced into Hakatere End moraine ridges. Outwash surface remnants are also mapped in Paddle Hill Creek, north of Mt. Guy and at Trig P near Hakatere Station. These surfaces all show very clear channelling and in most places several levels may be identified (see Chapters 14 and 15).

c) Meltwater Channel Deposits. This member is mapped in the Mesopotamia basin where the channels have been formed in association with the lateral and ablation moraines described above.

An extensive suite of Hakatere meltwater channels can be traced for 5.5 km south-south-east from Scour Stream to Forest Creek (J36/395192, S80/460845) (see Fig. 18). A series of nine major channels can be identified, ranging through 90 m altitude and across a zone up to 1 km wide.

Photo: V.C. Browne, CHCH. 45/103

FIG. 18. View west across the southern end of the Mesopotamia basin. Sinclair Range in background. Forest Creek Valley at left. P = Pyramid formation, DH = Dogs Hill formation, T = Trinity formation, H = Hakatere formation, S = Spider Lakes formation.

The channels range in width from a few metres to over 200 m across, and most are one-sided, their inner margins having been formed by the edge of the slowly shrinking Rangitata glacier. On the outer edges of some of the channels narrow, low lateral moraine ridges are preserved. A slightly younger series of Hakatere meltwater channels can be seen 180 m below this upper set. They occur across a zone 1.5 km wide and through a height range of 40 m. These channels are mostly two sided, up to 200 m wide and 30 m deep and have been cut through an earlier Hakatere ablation moraine surface.

d) Alluvial Fan Deposit Member. Alluvial fan surfaces, considered to have been formed during the Hakatere advance, are mapped in the Rangitata gorge and Pudding Valley. These fans are all clearly inactive and are graded onto Trinity or Hakatere outwash surfaces.

e) Landslide Deposit Member. One occurrence of this member is mapped at grid ref. Map 3, J36/658153, S91/744294 near the downstream end of the gorge. The landslide material can be traced up the valley side towards its source area 250 m above. The outer side has been truncated by the Rangitata River and younger terraces deposited 90 m below the general level of the landslide.

iii) Deposits

This formation is very poorly exposed, with deposits only being seen in the bank of Pudding Valley Creek below Low Hills.

a) Till Member. A small deposit of Hakatere till is exposed in Pudding Valley below the Low Hills (Map 3, J36/613201, S81/695348):

5 m non-bedded, sub-angular greywacke gravels up to 0.75 m across, in a coarse sand and silt matrix. Interpreted as till.

The exposure occurs beneath small, undulating ablation moraine. Although no other exposures of this member were seen, the presence of till beneath the various moraine surfaces may be assumed, as angular greywacke boulders up to 2 m across are littered over them.

b) <u>Outwash Deposit Member</u>. Two exposures of this member are visible beneath terraces in the true right bank of Pudding Valley Creek. At grid ref. Map 3, J36/613200, S81/695347 the following exposure occurs beneath a 45 m terrace at the downstream end of Pudding Valley:

1 m soil and loess.
8 m foreset bedded, rounded greywacke gravels up to 30 cm across, in a coarse sandy matrix.
5.5 m rounded greywacke gravels up to 20 cm across interbedded with lenses of fine sand up to 0.5 m across.
30 m horizontally bedded, rounded greywacke gravels up to 15 cm across, the upper 9.5 m of this unit being faintly iron stained.

The lack of weathering and stratigraphic position of these deposits suggests that they were deposited during the Hakatere advance. The lower 30 m of gravels dip slightly towards the Rangitata Valley and are interpreted as outwash derived from Pudding Valley. The overlying gravel and sand unit suggests that drainage to this valley became subsequently obstructed, presumably by the Rangitata glacier reaching into the head of the gorge and across the downstream end of Pudding Valley. The upper foreset bedded gravels dip up Pudding Valley, thus a small lake must have developed which was infilled by outwash gravels derived from the Rangitata glacier.

Three kilometres up the Pudding Valley at grid ref. Map 3, J36/589217, S81/669366, the following exposure occurs beneath an 11 m Hakatere terrace:

0.5 m soil and loess.

0.75 m horizontally bedded, subrounded greywacke gravels up to 15 cm across, in a sandy matrix. Interpreted as outwash deposits.

2 m laminated grey clays interpreted as lacustrine beds, interbedded with 0.5 m lenses of angular iron stained greywacke gravels up to 3 cm across, interpreted as slope deposits.

7.5 m horizontally bedded, subrounded greywacke gravels up to 20 cm across, in a coarse sand matrix. Interpreted as outwash deposits.

The lower unit of outwash gravels were probably deposited by meltwater flowing south down Pudding Valley from the Clearwater lobe glacier. They may also have been partly derived from the eastern flanks of the Harper Range. This phase of aggradation was interrupted by a period of ponding, presumably similar to that described above. This small lake was occasionally invaded by slope deposits from the nearby Harper Range. The gravel overlying the lake beds indicates that the lake was drained prior to the climax of the phase of aggradation. Although clearly of Hakatere age, this terrace cannot be precisely correlated with any particular member of the sequence of Hakatere moraines and outwash surfaces further down valley.

iv) Ice Extent

The extent of the Rangitata glacier during the Hakatere advance is shown in Figure 6. The main glacier filled the Mesopotamia basin to 1020 m a.s.l. and extended to the head of the gorge, where a small moraine remnant at grid ref. Map 3, J36/634169, S81/718312 (Map 5), 625 m a.s.l. marks its furthest extent. Some of the Hakatere deposits in Pudding Valley show evidence for ponding, indicating that ice in the gorge caused some blocking of the drainage of this tributary system. A small lobe of the glacier extended 1.5 km past Whiterock Station terminating about 550 m a.s.l.

The Clearwater lobe flowed through the Lake Clearwater basin, extending north around the base of Mt. Guy to within 1.5 km of the Ashburton River. It terminated at about 625 m a.s.l.

Each lobe of the glacier clearly advanced several times. However no attempt has been made to define a series of Hakatere advances, as the moraines and outwash surfaces of each lobe cannot be correlated.

3. EMILY FORMATION

i) Name and Distribution

The formation is named from Lake Emily (Map 3, J36/667381, S81/758543). Deposits are preserved around the margins of, and across the floor of the southern half of the Lake Heron Basin. They are also mapped in the Ashburton Valley and Big Hill Range.

Four members of the Emily formation are mapped: till, outwash, meltwater channel and alluvial fan deposits (Maps 1 and 3).

ii) Surface Form

The surface form of these deposits in the Lake Heron Basin is described and mapped in detail in Chapter 16 and Map 7. This section concentrates on those areas not covered in the later chapter.

a) Till Member. This is the commonest of the Emily formation members. Several different moraine types can be recognised and their original morphologies have only been slightly subdued.

Several suites of Emily end moraines are preserved across the Lake Heron basin (Map 7). They can be seen near the Maori Lakes, Johnstone Stream, Lake Emily and Rikki Spur. They consist of low ridges, less than 5 m high, some traceable for up to 3.5 km, and record the numerous active-ice frontal positions of the Rakaia distributary lobe glacier. In the Ashburton Valley a suite of Emily end moraines is festooned on the valley side near Boundary Stream (Fig. 19). Remnants of four moraine ridges formed by the Ashburton Glacier are preserved between 915 m - 865 m a.s.l. (Fig. 20). The ridges are up to 5 m high and are flanked on their outer sides by small meltwater channels. In the boundary of Valley Stream, 3.5 km to the west, almost perfectly preserved latero-terminal moraine loops extend from cirques in the Big Hill Range. Here the moraine ridges are up to 30 m high.

Lateral moraines formed during this advance can be seen on the eastern flank of the Lake Heron Basin north of Lake Heron, and along most of the western margin of the basin. A suite of lateral moraines can be traced for 7.5 km south from the Cameron River to Johnstone Stream (Map 7). Extensive areas of ablation moraine are also mapped north from Lake Emily to near the Swin River (Map 7).

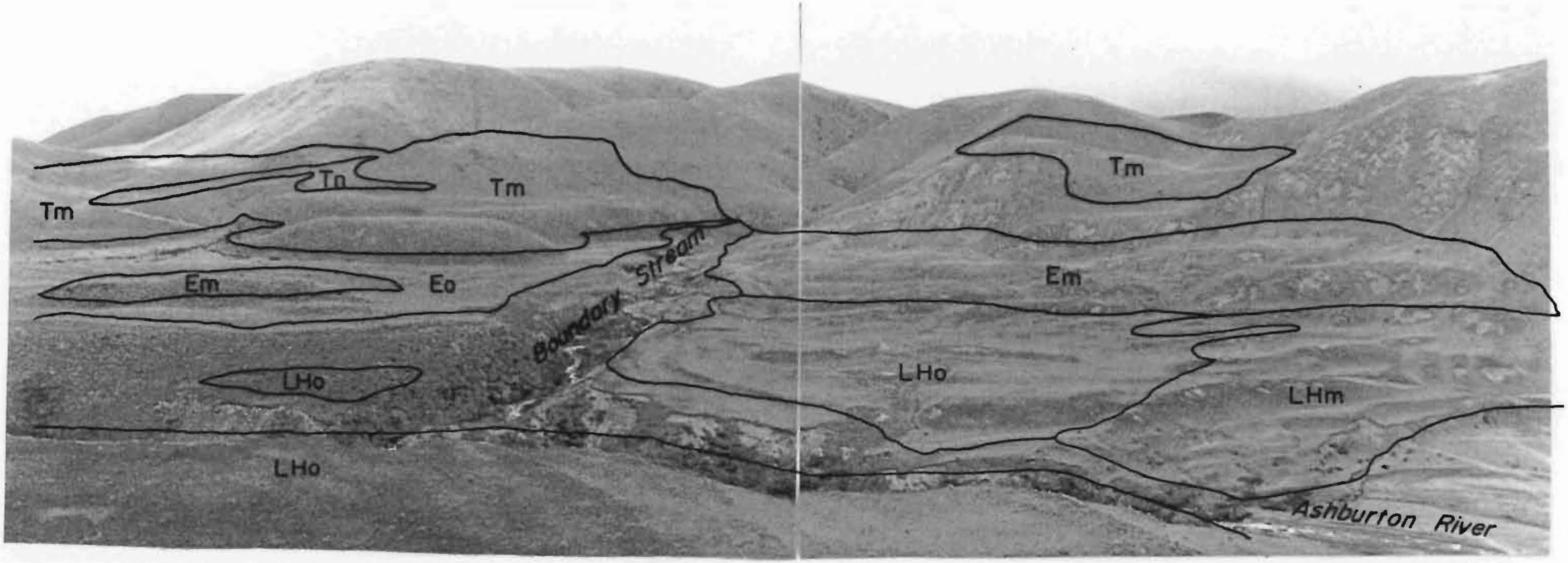


FIG. 19. View south of moraines and outwash surfaces in the Ashburton Valley. Ashburton River flows from right to left. Tm = Trinity moraine, Tn = Trinity alluvial fan, Em = Emily moraine, Eo = Emily outwash, LHm = Lake Heron moraine, LHo = Lake Heron outwash.

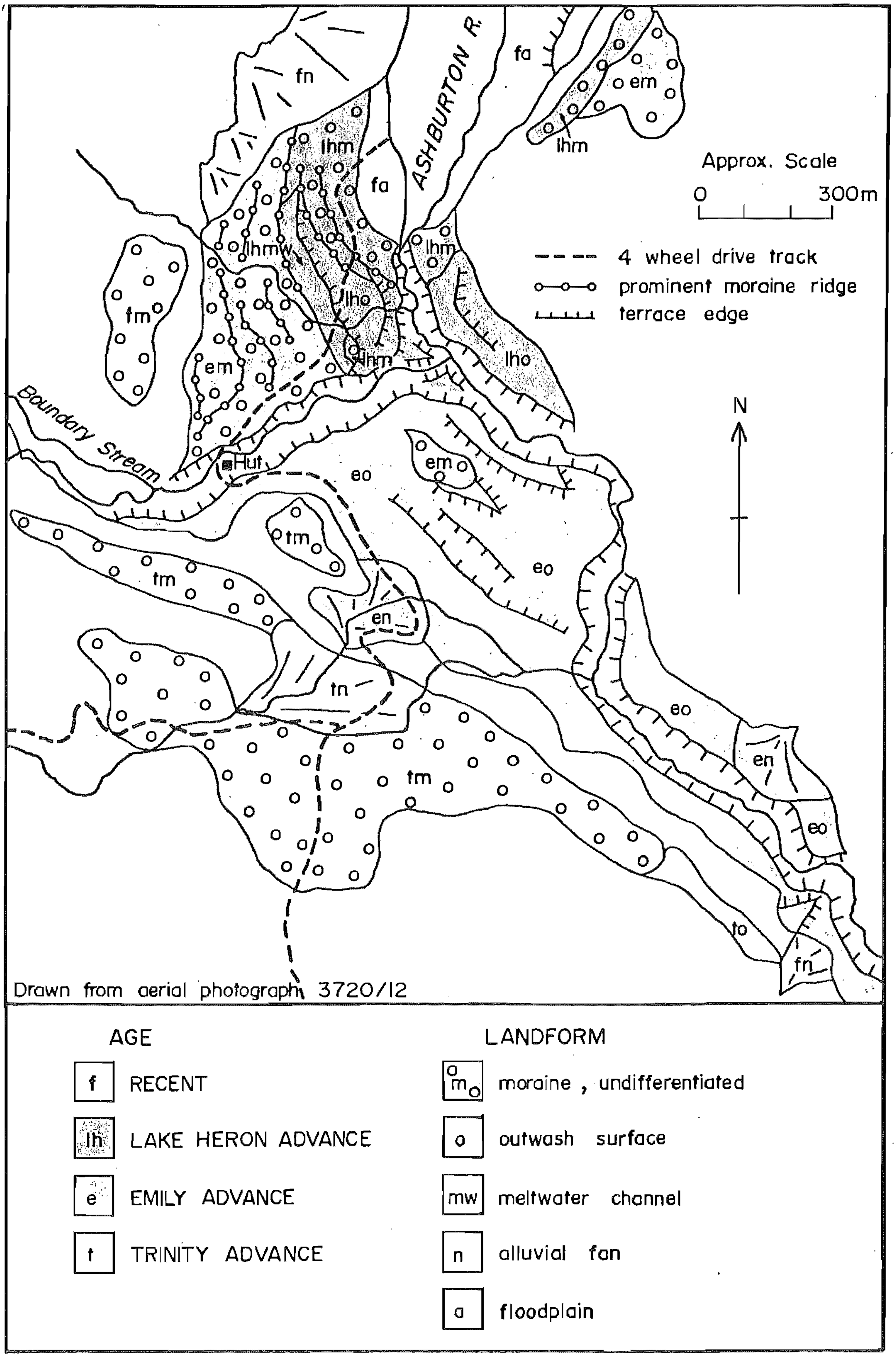


FIG 20: GEOMORPHOLOGICAL MAP OF PART OF THE UPPER ASHBURTON VALLEY

b) Outwash Deposit Member. In the Lake Heron basin Emily outwash deposits are mapped south of Johnstone Stream and near Lake Emily (Map 7). In the Ashburton Valley, a terrace 35 m above the river that runs south-eastwards for 1 km from Boundary Stream is mapped as Emily outwash. The surface is extensively channelled, and isolated small remnants of it can be traced down valley to the Lake Heron basin.

c) Meltwater Channel Deposits. Deposits of this member are mapped in one locality 2 km south-east of Lake Emily (Map 3). This and other occurrences of small Emily meltwater channels are mapped and described below (Chapter 16, Map 7).

d) Alluvial Fan Deposits. A small low angle alluvial fan on the western side of the Lake Heron basin (Map 1, J35/581439, S73/665608) partially overlaps a Trinity lateral moraine. It is included in the Emily formation.

iii) Deposits

No exposures of any of the members of the Emily formation were seen.

iv) Ice Extent

The extent of the Rakaia distributary lobe and Ashburton Glaciers during this advance is shown in Figure 6. The Cameron Glacier joined the Rakaia lobe at 1065 m a.s.l., nearly 400 m above the present basin floor. This lobe extended south almost to the Ashburton River, terminating at 640 m a.s.l., while a small lobe pushed past Lake Emily into the valley of the Stour River and terminated at 715 m a.s.l. The Ashburton Glacier limits are less clearly defined, however it probably extended about 1 km past Boundary Stream, ending at 855 m a.s.l.

The Emily advance was clearly a multiple event. There is evidence for four advances of the Ashburton Glacier, and the Rakaia lobe also advanced several times. Ice initially reached beyond Maori Lakes and Lake Emily, then readvanced to the area of Johnstone Stream (see Chapter 16).

4. AGE RELATIONSHIPS

The Hakatere and Emily formations are believed to have been contemporaneously deposited in adjacent valley systems. Both follow the Trinity advance and have a similar stratigraphic setting in relation to younger advances. Both sets of morphologies have been only slightly modified by post-formational processes. The distinction between the almost unmodified Hakatere-Emily moraines and the older, partially subdued Trinity moraines can be clearly seen 1.5 km west of Maori Lakes (Fig. 7).

The smaller ice extent, lack of weathering of the deposits, and relatively unmodified morphologies suggest that the Hakatere/Emily Advances are distinctly younger than the Trinity Advance. However, it is not known whether an interglacial or interstadial period separated this group of advances from the Trinity Advance.

5. BURNHAM FORMATION

i) Name and Distribution

The Burnham Formation is formally described by Suggate (1965, p. 18). It occurs close to the main rivers on the inner plains margin (Maps 3, 4), but extends to become the most widespread formation on the mid and lower plains area (Map 8). Alluvium and alluvial fan deposit members are mapped.

Only those areas of the Burnham Formation shown on Maps 3 and 4 will be discussed here. The plains area is more fully treated in Chapter 17.

ii) Surface Form

a) Alluvium Member. The Burnham Formation can be traced from the downstream end of the Rangitata gorge for 52 km south-east to the present coastline. Its surface form is that of a very large low-angle multi-storey alluvial fan. The highest surface is on the north bank of the Rangitata River. At the gorge mouth it is 70 m above the river (427 m a.s.l.) and it declines to be approximately 38 m above river level near Peel Forest settlement. Except for two slightly lower terraces 4.5 km from the gorge, the Burnham Formation consists of a single surface on this northern bank of the river. It overtops the older Windwhistle Formation 13.5 km from the gorge, and extends eastwards for 16 km to the Hinds River, sloping away from the Rangitata River by up to 60 m. On the south bank of the river the Burnham Formation is less continuously preserved. Here several terrace levels are preserved, all lower than on the north bank. From the gorge south for 6.5 km the main surface is 60 m above the river.

At Peel Forest, 14 km from the gorge, it is 25 m above the river and extends westwards for 2.5 km to Coopers Creek, this distance increasing southwards to be 6 km at the coast.

To the north the Burnham Formation can be traced down the Ashburton sector of the plains from near the Stour River to the coastline. Its surface form consists of a very broad flood-plain surface extending from the northern margin of the Rangitata fan, along the Hinds River, north-eastwards for 15 km to the southern margin of the Rakaia fan, along the South Branch of the Ashburton River. A single surface can be identified 3 m above the Ashburton River near the inner plains margin.

b) Alluvial Fan Deposit Member. Several small alluvial fans that grade onto the alluvium member of the Burnham Formation are mapped. These mostly occur near the downstream end of the Rangitata Gorge. Most have been deeply incised.

iii) Deposits

The alluvium member of the Burnham Formation is exposed at grid ref. Map 4, J36/658153, S91/788246 next to the Rangitata Diversion Race:

15 m horizontally bedded, rounded greywacke gravels up to 30 cm across, in a sandy matrix.

The gravels are unweathered and are interpreted as alluvium.

iv) Age

The various Burnham Formation surfaces along the inner plains margin can be correlated largely on the basis of their height relationships. The Ashburton surface can be traced to the Hinds River where it is at the same height as the Rangitata surface. Those on the south bank of the Rangitata River are included in this formation as they occur above the younger St. Bernard Formation surfaces.

The Burnham Formation cannot be traced continuously through either the Rangitata or Ashburton gorges to the moraine sequences in the intermontane basins (see Fig. 9 and Chapter 17). The correlation of this formation with the Hakatere and Emily Formations rests mainly on its stratigraphic setting in relation to other formations. Through the Rangitata gorge the next youngest St. Bernard Formation can be correlated with the Spider Lakes formation (Chapter 11), and through the Ashburton Gorge the next older Windwhistle Formation can be correlated with the Trinity formation (Chapter 9). The correlation of the Burnham Formation with the Hakatere and Emily formations is also supported by the similarity of weathering of the deposits and the lack of modification of the original morphologies.

CHAPTER 11

THE SPIDER LAKES AND LAKE HERON ADVANCES

1. INTRODUCTION

The deposits of these two advances record the youngest Late Pleistocene glacial events in the study area. The deposits of the Spider Lakes Advances of the Rangitata glacier are mapped as the Spider Lakes formation. The deposits of the Lake Heron Advances are mapped as the Lake Heron formation. Both of these formations are confined to the intermontane basins. On the inner margin of the Canterbury Plains, deposits considered to have formed contemporaneously are mapped as the St. Bernard Formation. Correlatives of these formations in the upper Rakaia Valley are mapped as the Acheron formation.

2. SPIDER LAKES FORMATION

i) Name and Distribution

The formation is named from the Spider Lakes (Map 3, J36/583320, S81/665476). Deposits are extensively preserved around the lower margins and across the floor of the Lake Clearwater basin. They can also be seen in the main Rangitata Valley near the upstream end of the gorge and at lower levels in the Mesopotamia basin.

Five members of the Spider Lakes formation are mapped;

till, outwash, meltwater channel, alluvial fan and lake deposits. Two age classes are also recognised: deposits formed during the period of ice advance and those formed during the period of ice retreat. Deglacial deposits are labelled with a super script thus: $\overline{st}$, $\overline{so}$ etc.

ii) Surface Form

The surface form of Spider Lakes formation deposits in the Lake Clearwater basin, and at the head of the Rangitata Gorge, is shown in detail on Maps 5 and 6 and is described more fully in Chapters 14 and 15. This section concentrates on those areas not covered in these later chapters.

a) Till Member. A variety of moraine types can be recognised, all of which show little defacement of their original surface form.

In the Rangitata Valley remnants of three end moraine loops can be identified near the head of the gorge (Map 5, Chapter 14). Extensive remnants of a set of three end moraine loops of the Clearwater lobe are preserved across the eastern end of the Lake Clearwater basin. They extend around the base of Mt. Guy and across to the head of Pudding Valley (Map 6, Chapter 15).

Lateral moraines of these advances are widespread, occurring around the lower margins of the Lake Clearwater basin (Map 6) and in the Rangitata Valley near Whiterock Station and on the Low Hills (Map 5). In the Mesopotamia basin two areas of Spider Lakes advance lateral moraines are preserved. A small ridge 3 m high and 8 m across can be traced for 2.5 km south from grid ref. Map 2, J36/372286, S80/43445. This ridge, at 825 m a.s.l., marks the upper limit of Spider Lakes ice at the north-western end of the Mesopotamia basin, and 7 km south near Forest Creek a suite of three lateral moraines is preserved. The upper ridge, which is up to 4 m high and 20 m wide, cuts across an older, higher Hakatere ablation moraine surface. It can be traced discontinuously for 2.5 km south-east from grid ref. Map 2, J36/411222, S80/475375 to near trig E (Fig. 18). At 1.5 km to the north and 75 m below, a prominent pair of moraine ridges can be seen. They run for 1.8 km south-east from grid ref. Map 2, J36/425232, S80/491385. The two ridges are up to 4 m high and are 90 m apart. In cross-profile the outer ridge of this pair has a short, steep distal slope and a longer, flatter proximal slope. It is interpreted as a push moraine (Andrews 1975). The inner moraine has short, steep proximal and distal faces and is interpreted as a dump moraine (Andrews 1975). This configuration of moraine ridges suggests that the ice margin advanced to the outer push moraine, then rapidly retreated a short distance, maintaining this new position whilst the dump moraine was formed. At 350 m north-east and 15 m below this pair of ridges a third lateral moraine can be seen. It is up to 2 m high and runs parallel to the upper pair of ridges. Other lateral moraine ridges associated with the main Rangitata glacier are preserved along the south-western flanks of the Harper Range. At grid refs. Map 2, J36/470274, S80/540430; J36/487242, S81/558395 and J36/483270, S81/555425 small Spider Lakes Advance lateral moraine remnants clearly cut across older, higher ridges. These three moraine remnants are 120 m above the highest Spider Lakes ice marginal features in the Mesopotamia basin, as shown on Figure 9. This would suggest that the Rangitata glacier was able to spread laterally into the basin so that its western margin became substantially lower than its eastern or Harper Range margin.

Lateral moraine suites can also be seen in numerous valleys that feed into the Rangitata River from the foothill ranges. The most striking is the latero-terminal suite of Spider Lakes moraine ridges flanking Power House Stream (Map 2, J36/445392, S80/515560). Other lateral moraines are mapped in the Potts Valley, Bush Stream, Forest Creek and other valleys that drain from the Two Thumb Range.

Extensive areas of ablation moraine formed during the retreat of Spider Lakes ice can be identified in the Lake Clearwater basin (Chapter 15, Map 6). The bulk of the till mapped in the Mesopotamia basin has a gently undulating surface topography with numerous closed depressions containing swamps and ponds (Fig. 21). These surfaces are interpreted as ablation moraine. At lower levels in the basin, between 535 m - 485 m a.s.l. the ablation moraine surfaces contain a number of irregular ridge features running sub-parallel to the valley axis. From near Tui Stream to Forest Creek, remnants of six ridges ranging from 0.2 km - 1.5 km long can be seen. The most prominent ridge occurs to the north-west near Mesopotamia station, and runs for 2.8 km south-east from grid ref. Map 2, J36/393279, S80/456437 to Scour Stream. The ridge is steep sided, up to 20 m wide and 10 m high, and follows a highly irregular route across the downs. These ridges are interpreted as dump moraines formed at the margin

Photo: V.C. Browne, CHCH. 11484.

FIG. 21. View north across the Mesopotamia basin and Rangitata River. Clyde River in background.

of the retreating Rangitata glacier during periods of still stand of the ice front.

b) Outwash Deposit Member. Small outwash surface remnants are mapped in association with the end moraines of both the Clearwater lobe and main Rangitata glacier. These are described below (Chapters 14 and 15). Spider Lakes outwash is also mapped in the Potts Valley. Three levels can be recognised between 105 m - 75 m above river level. The highest consists of a 120 m wide terrace on the north bank at grid ref. Map 1, J35/443470, S72/515645. Two similar but slightly lower terraces occur on the opposite bank of the river. These terraces are at a height consistent with their being outwash surface remnants originating from the Spider Lakes moraines preserved 1.5 km up valley.

c) Meltwater Channel Deposits. Deposits of this member are mapped in the Lake Clearwater basin (see Chapter 15 and Map 6) and at the head of the Rangitata gorge (see Chapter 14 and Map 5). During both the advance and retreat phases of the Spider Lakes Advance meltwater channels were active in the Mesopotamia basin (Map 2, Figs 18 and 21). South-east for 5.2 km from Scour Stream, the upper limit of Spider Lakes deposits in this part of the basin is marked by a prominent meltwater channel. It is up to 150 m wide and 30 m deep. Over most of its length it is two sided, flanked on its inner side by Spider Lakes ablation moraine. However over its southern 0.7 km it is one-sided and appears to swing eastwards inside the line of lateral moraine described above (pp. 93-94). This suggests that from here the meltwater may have flowed subglacially. A number of meltwater channels are mapped in this area between the upper Spider Lakes lateral moraine and the next lower moraine doublet (see Map 2). These channels are up to 60 m deep and are the deepest in the Mesopotamia basin. They may all have been partly formed subglacially prior to use as the ice level fell, thus becoming overdeepened.

Most of the metlwater channels in the basin are aligned sub-parallel to the axis of the Rangitata Valley. They are mostly two-sided and contain numerous small terraces indicating several periods of downcutting controlled by the steadily declining ice level.

d) Alluvial Fan Deposit Member. Isolated occurrences of this member are mapped in the Forest Creek and Potts Valleys. They generally grade onto Spider Lakes outwash surfaces and have been heavily truncated. In the main Rangitata Valley the truncated alluvial fan at grid ref. Map 2, J36/354368, S80/415535 was probably built up against the margin of the shrinking Rangitata glacier.

e) Lake Deposit Member. This member is mapped in the Rangitata Valley upstream from the gorge. On the south bank of the river between Coal Creek and Rawtor Creek, two low terraces approximately 17 m and 10 m above river level are underlain by lake deposits (see below). No lake benches are present and the surfaces slope down valley. They are interpreted as terraces cut in lacustrine deposits presumably during successive stages of draining of the lake. It is not known whether the lake beds represent a single episode of ponding in the Rantitata Valley, or several periods of ice marginal ponding during the retreat after the Spider Lakes advances.

iii) Deposits

Exposures of this formation are not common; however representative exposures of the till, outwash, meltwater channel and lake deposit members were observed.

a) <u>Till Member</u>. Spider Lakes till is exposed in the Rangitata Valley near Whiterock Station. In a stream bank at grid ref. Map 3, J36/622164, S81/703308 the following section appears:

12 m non-bedded, angular greywacke gravels up to 1 m across, in a coarse sand-clay matrix, grading into
13 m horizontally bedded, subrounded greywacke gravels up to 20 cm across, in coarse sand matrix.

This exposure occurs beneath the uppermost Spider Lakes advance lateral moraine. The upper unit is interpreted as till, and the lower unit is interpreted as proximal outwash deposited immediately prior to the first Spider Lakes advance. At grid ref. Map 3, J36/620168, S81/702311 the following section shows beneath a Spider Lakes lateral moraine ridge:

1 m loess and soil.
8 m non-bedded, subrounded, poorly sorted greywacke gravels up to 0.75 m across, interpreted as till. Unconformably overlying
8 m horizontally bedded, rounded, iron stained greywacke gravels up to 10 cm across. Interpreted as fluviatile deposits.

These lower gravels are clearly significantly older than the overlying till. The weathering suggests that they may be as old as the Pyramid or Dogs Hill formations. Twenty-seven kilometres up valley near Black Birch Creek (grid ref. Map 2, J36/381318, S80/444480) the following exposure can be seen (Fig. 22):

7 m non-bedded, sub-angular, unweathered greywacke gravels up to 1.5 m across, in a sandy clay matrix. Interpreted as till.

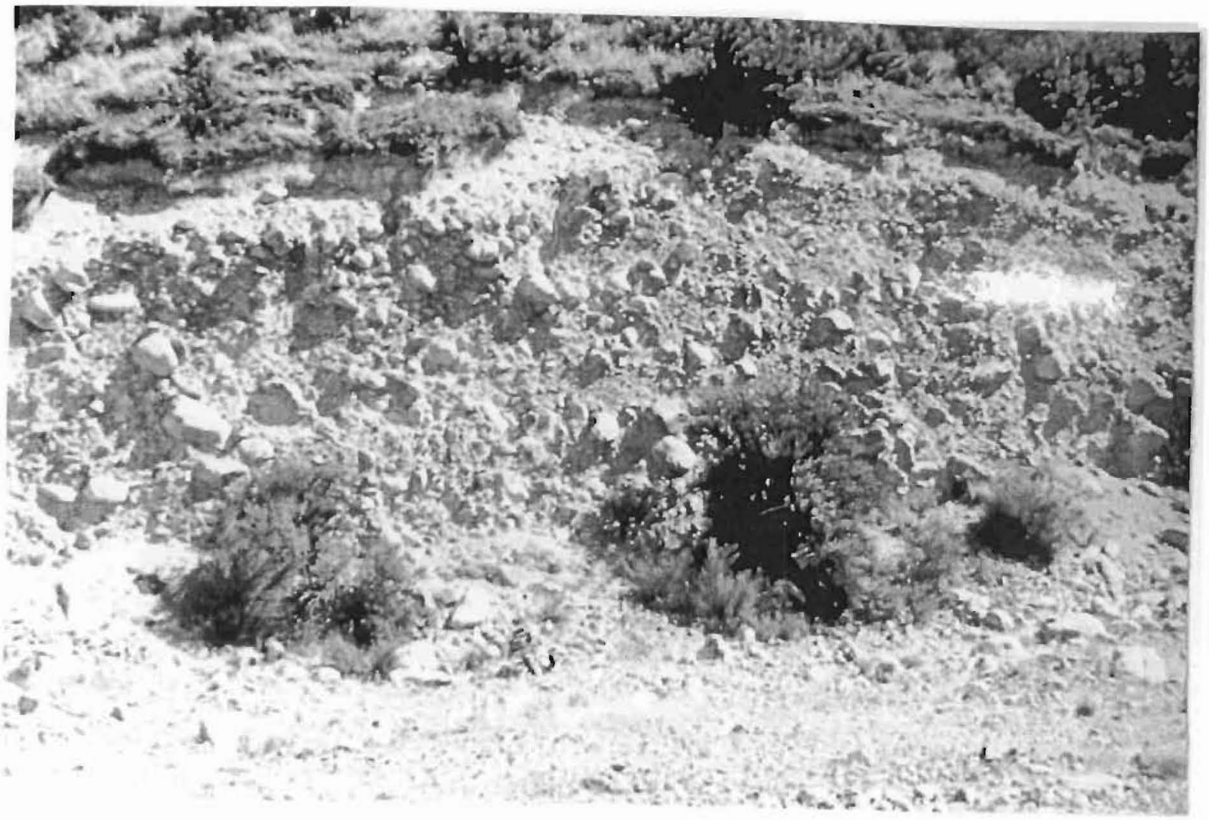


FIG. 22. Spider Lakes formation till near Black Birch Creek, Rangitata Valley.

b) <u>Outwash Deposit Member.</u> One exposure of this member was seen at the head of the Rangitata Gorge. At grid ref. Map 3, J36/635171, S81/719314 the following section appears beneath a 29 m terrace on the south bank of the Rangitata River:

0.5 m loess and soil.
2 m coarse sand.
14.5 m horizontally bedded, rounded, slightly rusty greywacke gravels up to 4 cm across, in a coarse sand matrix. Interpreted as outwash.
12 m irregularly bedded, sticky grey, organic rich clays. Interpreted as lacustrine beds. Base not seen, however the clays continue to at least 2 m further below river level.

The terrace surface can be traced 1 km up valley to a late Spider Lakes advance moraine complex (Chapter 13). Thus the gravel unit is interpreted as outwash material, probably derived from nearby exposures of the weathered gravels described above (p. 99). The sticky grey clays which are horizontally bedded, with individual beds being up to 1 cm thick, are exposed over a distance of 200 m. Parts of this unit show steep dip directions both up and downvalley. However the exposures are poor, and precise relationships cannot be determined. The variable dip directions are probably post-depositional and could be related to the melt-out of an underlying ice body. The lake was probably dammed behind an ice cored moraine, remnants of which can be seen 0.75 km downvalley at grid ref. Map 3, J36/637170, S81/723313. Organic matter is common in the upper part of the clay unit, particularly between 2 m - 5 m above the river. The organic material consists of broken plant and leaf remains, wood fragments and small branches up to 0.2 × 1 m. Some of the woody material is charred. Also preserved in small numbers are freshwater molluscs of the genus *Hyridella menziesi* (Winterbourn 1973). Pollen samples taken from within the lake beds at 3.5 m and 12 m above river level were analysed by Dr N.T. Moar (see Appendix 1). The upper sample "...presumably represents a cold phase..." (Moar, *pers. comm.*), while the lower is suggestive of "...less extreme conditions..." (Moar, *ibid.*). This would suggest that the lake formed during an interstadial period within the Spider Lakes advance. Conditions deteriorated towards the end of the period of lake sedimentation as the Rangitata glacier readvanced and outwash gravels were deposited over the lacustrine beds.

c) Meltwater Channel Deposits. In the Mesopotamia basin at grid ref. Map 2, J36/375289, S80/437448 deposits beneath a Spider Lakes meltwater channel are exposed. The section which occurs in the south bank of Bush Stream near the north-western margin of the basin is partly obscured by slope wash.

20 m	horizontally bedded, rounded greywacke gravels up to 50 cm across, in a coarse sand matrix. Interpreted as meltwater channel deposits.
30 m	non-bedded, poorly sorted, subrounded greywacke gravel up to 1 m across, with isolated lenses of laminated fine sands up to 1 m thick. Interpreted as till. Grades into
30 m	foreset bedded, rounded greywacke gravels grading from 5 cm at base to 30 cm at top.
12 m	horizontally bedded, medium sand.

There are no obvious erosional breaks in these sediments. The lower units of this section are considered to represent a transition from quiet water lacustrine sedimentation to deltaic deposition. The foreset beds dip eastwards into the

Rangitata Valley so they were probably deposited by Bush Stream. The increasing grain size in this unit suggests an increase in tempo of deposition until the site was invaded by ice. Till deposition continued as the ice level rose, with brief periods of localised ponding, until a meltwater channel became established between the Rangitata glacier and the valley side. This drainage was probably from Bush Stream. At 6.5 km south-east from here, deposits beneath a younger meltwater channel can be seen in a stream bank (Map 2, J36/420242, S80/485396).

4 m horizontally bedded, rounded greywacke gravels up to 20 cm across, in a coarse sand matrix. Interpreted as meltwater channel deposits.

15 m horizontally laminated, pale grey clays interpreted as lake bottom beds.

6 m non-bedded, sub-angular greywacke gravels up to 30 cm across in a sandy clay matrix, interpreted as till.

The nature of the contacts between these units is obscured. The relationship between the lake beds here and the lacustrine deposits described above cannot be determined. However, as the latter occur at a higher level in the basin, they are presumably related to an earlier Spider Lakes advance. Meltwater channel deposits are also exposed in the Lake Clearwater basin in the eastern bank of the Potts River. At grid ref. Map 2, J36/485373, S81/559538 the following section appears beneath a late Spider Lakes Advance meltwater channel:

1 m loess and soil.

3 m horizontally bedded, rounded, unweathered greywacke gravel up to 50 cm across. Interpreted as meltwater

channel deposits.

20 m non-bedded, sub-angular, grading upwards to subrounded, unweathered greywacke gravels and boulders up to 1.5 m across. Interpreted as till.

35 m horizontally bedded, sub-angular and subrounded, yellow-brown greywacke gravels, grading upwards from 2 cm to 30 cm. Interpreted as fluvial deposits. Unconformably overlying

8 m horizontally bedded, pale grey clays. Interpreted as lake beds.

20 m non-bedded, poorly sorted, angular, unweathered greywacke gravels up to 1.5 m across. Interpreted as till.

15 m horizontally bedded, pale brown-grey silts, with lenses of angular greywacke gravels up to 15 cm across. Interpreted as lake beds.

+2 m poorly exposed gravels interpreted as till.

This deep exposure records a complex history of glacial, fluvial and lacustrine sedimentation at the western end of the Lake Clearwater basin. The upper two gravel units clearly belong to the Spider Lakes formation. The thick unit of weathered gravels is interpreted as weathered material reworked by the Potts River, during an interstadial interval in the Spider Lakes Advance or after the Hakatere Advance. The lower gravel units are not significantly weathered and are thus presumed to be Hakatere deposits.

d) Lake Deposits. Lake deposits are confined to the Rangitata Valley between the gorge and Ben McLeod Station.

At grid ref. Map 3, J36/506207, S81/577358 the following section is visible beneath a terrace 6 m above river level:

1.3 m massive, white, very fine silt unconformably overlying
0.3 m cross bedded, pale grey coarse sand unconformably overlying
1 m horizontally bedded clays interbedded with medium sand layers up to 1 cm thick.
Base not seen.

All three units are interpreted as lacustrine deposits. The variations in sedimentation pattern presumably relate to fluctuations of the nearby ice front.

Several other very small exposures of clays and silts were seen downvalley from here in track cuttings and terrace edges. However, stratigraphic relationships have been obscured. The lake deposits can be traced as far as the head of the Rangitata Gorge. They are not considered to be the same as the lake beds described from beneath the Spider Lakes outwash surface at grid ref. Map 3, J36/635171, S81/719314. These latter have a much finer grain size and occur beneath a restricted terrace level some 12 m higher above river level. The younger lacustrine beds probably relate to a period of ponding of the Rangitata River that occurred when the glacier had retreated back up valley into the Mesopotamia basin. No evidence for a damming mechanism could be found. The ponding may have been caused by an ice cored moraine dam or a small landslide at the head of the gorge.

iv) Ice Extent

The extent of the Rangitata glacier during this, the smallest and latest Late Pleistocene glacial advance, is shown in Figure 6. The main glacier filled the Mesopotamia basin to 800 m a.s.l. and extended to the head of the gorge to a moraine remnant at 450 m a.s.l. The lacustrine beds described above suggest that the presence of ice in the Rangitata Valley downstream of Forest Creek caused substantial ice marginal ponding of meltwater in the Mesopotamia basin.

The Clearwater distributary lobe flowed through the Clearwater basin and extended to within 2.5 km of the Ashburton River. It terminated at about 640 m a.s.l.

Each lobe of the glacier advanced three times. These advances and the final retreat of the glacier are described in more detail in Chapters 14 and 15.

3. LAKE HERON FORMATION

i) Name and Distribution

The formation is named from Lake Heron (Map 1, J35/622459, S73/710630). Deposits are preserved around the lower margins and across the floor of the northern half of the Lake Heron basin. They are also mapped in the Ashburton Valley and Big Hill Range (Maps 1, 3).

Five members of the Lake Heron formation are mapped: till, outwash, meltwater channel, and alluvial fan deposits. Two age classes are also recognised: deposits formed during the period of ice advance and those formed during the period of ice retreat. Deglacial deposits are labelled with a superscript thus: $\overline{\text{lht}}$, $\overline{\text{lho}}$ etc. (see Map 1).

ii) Surface Form

The surface form of deposits in the Lake Heron basin is shown in detail on Map 7 and is described more fully in

Chapter 16. This section concentrates on those areas not covered in these later chapters.

a) Till Member. A variety of moraine types can be recognised, all of which show little modification of their original surface form.

In the Lake Heron basin remnants of three end moraine loops can be seen between 1.5 km - 2 km south of Lake Heron (Map 7, Chapter 16). In the Ashburton Valley a suite of three Lake Heron advance end moraine remnants are preserved immediately below the Emily moraines (Map 1, J35/544408, S81/624575, Figs 19, 20). The ridges which occur between 28 m - 35 m above river level are up to 3 m high and are separated by meltwater channels. Latero-terminal moraine ridges of the Lake Heron Advances are also mapped 5 km to the north-west in the Big Hill Range.

Extensive suites of Lake Heron Advance lateral moraines can be seen along the lower flanks of the northern part of the Lake Heron basin (Map 7). These occur up to 1050 m a.s.l. and clearly cut across the older Emily moraines. Large areas of ablation moraine are preserved around the southern shores of Lake Heron (Map 7, Chapter 16).

b) Outwash Deposit Member. Outwash deposits of the Lake Heron formation are mapped south from the end moraines around Lake Heron (Map 7, Chapter 16). A small area of outwash is mapped in the Ashburton Valley on the north bank of the river (Map 1, J35/547407, S81/627574). This terrace, which is 30 m above the river, is deeply channelled.

c) Meltwater Channel Deposit Member. This member is mapped around the southern shores of Lake Heron. The channels cut through the Lake Heron end and ablation moraines, and were mostly formed during the final retreat of the Rakaia lobe glacier (Map 7, Chapter 16).

d) Alluvial Fan Deposit Member. Lake Heron formation alluvial fans are mapped in a number of areas, including the Ashburton, Cameron and Lake Stream Valleys, and in the small valleys that drain into the Lake Heron basin from the mountains to the east. Most of these fans are truncated and no longer active.

iii) Deposits

This formation is very poorly exposed, with only one exposure of the till member being seen.

a) Till Member. On the southern shore of Lake Heron at grid ref. Map 1, J35/621446, S73/709615 the following section is exposed:

0.75 m loess and soil.
3.25 m non-bedded, poorly sorted, sub-angular greywacke gravel up to 30 cm across. Interpreted as till.

iv) Ice Extent

The extent of the Rakaia distributary lobe and Ashburton Glaciers during this advance is shown in Figure 6. The Cameron Glacier joined the Rakaia lobe 4 km to the west of Lake Heron at 915 m a.s.l. This combined lobe extended 6.5 km south and terminated at 700 m a.s.l. The Ashburton Glacier extended as far as Boundary Stream, ending at 850 m a.s.l.

There appear to have been three main advances within the Lake Heron advance. Three closely spaced end moraines can be seen associated with both the Rakaia lobe and Ashburton glaciers.

v) Age Relationships

The Spider Lakes and Lake Heron formations are believed to have been contemporaneously deposited in the adjacent valley and intermontane basin systems. Both represent the smallest of the major advances preserved in the study area, occurring up valley from the older Emily and Hakatere advances. Morphologies are well preserved and the deposits show little weathering. The distinction between the Hakatere/Emily and Spider Lakes/Lake Heron formations is based largely on the different ice extents, as both sets of deposits show very little weathering or modification of their original surface form. Thus there was presumably only a brief interstadial interval between these two sets of advances.

4. ST. BERNARD FORMATION

i) Name and Distribution

The St. Bernard Formation is formally described by Suggate (1965, p. 18). It occurs downstream of the Rangitata gorge and is of limited extent. Alluvium and alluvial fan deposit members are mapped. These occurrences are too small to be shown on Map 8.

ii) Surface Form

a) Alluvium Member. A number of low terraces occurring on both the north and south banks of the Rangitata River for 8 km downstream of the gorge are mapped as the St. Bernard Formation. These terraces, which occur between 45 m - 25 m above river level, are discontinuous and show clear surface channelling.

b) Alluvial Fan Deposit Member. Three occurrences of this member are mapped. They can be seen on the south bank of the Rangitata River where it is joined by Raules Gully, Middle Stream and Chapman's Creek. The fans deposited by these small streams grade onto terraces of the St. Bernard Formation alluvium member. All three have been truncated by the Rangitata River and incised by the small streams.

iii) Deposits

No exposures of the deposits of this member were seen.

iv) Age

The St. Bernard Formation surfaces along the Rangitata River can be separated from the older Burnham Formation largely on the basis of their lower altitude (Fig. 9). These surfaces cannot be traced continuously upstream into the Rangitata Gorge, however sufficient remnants are present in the gorge to enable the St. Bernard Formation to be confidently correlated with the outwash member of the Spider Lakes formation (see Figs 9 and 23).

FIG. 23. The Rangitata Gorge. The lower terraces are mapped in the Spider Lakes formation.

CHAPTER 12

HOLOCENE FORMATIONS

1. INTRODUCTION

This thesis is concerned primarily with Late Pleistocene events and their associated deposits, formed up to the time of the last major retreat of the valley glaciers.

However, Holocene deposits relating to more recent glacial advances have been recognised in the upper reaches of all the major valleys in the study area. It is considered important that these be shown in relation to the Late Pleistocene formations already described. There is also a wide variety of recently formed and presently forming deposits in the field area, which are relevant in view of the potential for modifying and obscuring earlier deposits.

The Pleistocene/Holocene boundary is informally defined in this study as falling after the last major retreat of the glaciers but before a significant re-advance that formed moraines about two-thirds of the distance up valley from the Pleistocene moraines. Thus the boundary falls between the Spider Lakes/Lake Heron deglaciation and the Two Thumbs/ Wildman/Lake Stream advances described below.

The Holocene formations consist of glacial, fluvio-glacial, alluvial and mass movement deposits. They are mainly confined to the upper reaches of the main valley systems and close to the larger rivers. Two age classes are recognised; deposits formed during the earliest Holocene glacial advances and those formed after these events. The former are mapped using informal formation names, while the latter are all classed as Recent deposits.

On Maps 1-2 Holocene deposits in the Upper Rakaia, Cameron, Ashburton, Potts and Upper Rangitata valleys have been mapped at a reconnaissance level using aerial photographs and the published descriptions of Burrows (1975), and Burrows and Russell (1975). However these deposits in the Lawrence, Clyde and Havelock rivers, which are presently being studied by Burrows and Gellatly (*in prep.*) have not been mapped.

Most of these deposits occur towards the heads of the main valley systems. Field checking of the mapping was not possible, thus descriptions of features are brief and no exposures are described.

2. EARLY HOLOCENE FORMATIONS

Four early Holocene formations are mapped: the Lake Stream Formation in the Rakaia Valley; the Wildman formation in the Cameron, Ashburton and Potts valleys; the Two Thumb formation in the Rangitata Valley; and the Springston Formation along the inner plains margin.

i) The Lake Stream Formation

a) Name and Distribution. The formation is named from Lake Stream which flows north from Lake Heron to the Rakaia River. Deposits are preserved in the Lake Stream and Rakaia valleys (Map 1). Three members are mapped;

till, outwash and alluvial fan deposit members.

b) Surface Form. The surface form of the till and outwash members is described by Burrows and Russell (1975).

1. Alluvial Fan Deposit Member. Several multi-storey alluvial fans can be seen in the Lake Stream and Rakaia valleys. These have all been heavily truncated and deeply incised. Only the lower surfaces show signs of recent activity. Most have three distinct levels, and the middle fan surfaces are here interpreted as belonging to the Lake Stream formation.

2. Lake Beaches. Burrows and Russell (1975, Fig. 2) map lake beaches formed around the shores of "Greater Lake Heron" dammed by the Rakaia Glacier blocking the end of the Lake Stream Valley during the Lake Stream advance. These beaches in the middle and lower part of the Lake Stream Valley were not visited in the field and could not be located by a detailed aerial photograph examination. "Greater Lake Heron", as described by Burrows and Russell (1975, p. 468), reached a level of 713 m - 689 m a.s.l. However Lake Stream moraines in the Rakaia Valley, as mapped by Burrows and Russell (1975), indicate that the ice blocking the Lake Stream Valley only reached 655 m a.s.l., well below the suggested lake level. The mechanism for damming at 713 m - 689 m a.s.l. is not seen, thus the existence of a "Greater Lake Heron" at the time of this advance is doubtful. Drainage from the Lake Stream Valley could easily have escaped subglacially, as the Rakaia Glacier extended less than 1 km past the end of the valley. The lake beaches described by Burrows and Russell around the shores of Lake Heron and elsewhere are presumably older and

relate to smaller pro-glacial lakes formed during the retreat of the Rakaia lobe glacier after the Lake Heron advance (see Chapter 16).

c) Ice Extent. During the Lake Stream advance the Rakaia glacier extended 0.75 km down valley from the end of the Lake Stream valley, and terminated at about 610 m a.s.l. The advance is believed to have occurred shortly after 11,900 yrs B.P. (Burrows and Russell 1975).

ii) Wildman Formation

a) Name and Distribution. The formation is named from Wildman's Hill, a peak between the Cameron and Ashburton rivers. Deposits are preserved in the Cameron, Ashburton and Potts valleys (Map 1). Two members are recognised: till and alluvial fan deposits.

b) Surface Form.

1. Till Member. The surface form of the till member in the Cameron and Ashburton valleys is described by Burrows (1975). In both valleys two end moraine loop remnants can be recognised. In the Potts Valley the moraine remnants at grid ref. Map 1, J35/433523, S72/505705 are mapped as the Wildman formation.

2. Alluvial Fan Deposit Member. In the Cameron and Ashburton valleys several alluvial fans that have been truncated and are no longer active are included in the Wildman Formation.

c) Ice Extent. During the Wildman advances the Cameron Glacier extended to grid ref. Map 1, J35/521556, S72/602738 terminating at 1040 m a.s.l., the Ashburton Glacier reached to grid ref. Map 1, J35/479542, S72/556723 ending at 1130 m a.s.l., while the Potts glacier extended to grid ref. Map 1, J35/430521, S72/502701 terminating at 1120 m a.s.l. These advances are believed to have occurred prior to 9520 yrs B.P. (Burrows 1975).

iii) Two Thumb Formation

a) Name and Distribution. The formation is named from the Two Thumb Range. Deposits are preserved near the confluence of the Havelock and Clyde Rivers and in the Two Thumb Range (Map 2). A till member is recognised.

b) Surface Form.

1. Till Member. Remnants of lateral moraines of this advance are preserved in the Clyde and Havelock valleys. Near Erewhon Station a ridge complex can be traced for 3.5 km south from Tank Gully (Map 2, J35/372443, S72/437617) to Caroline Stream. Two ridges up to 60 m wide and 20 m high can be clearly seen to cut across the older Spider Lakes moraines. On the western bank of the Clyde River similar lateral moraine ridges can be traced for 3.5 km to Trig I. In the Havelock Valley lateral moraine ridges can be traced for 5.5 km south-east from Cloudy Stream to Trig I where they merge with the Clyde Valley moraines. In the main Rangitata Valley a small hummock at grid ref. Map 2, J36/315377, S80/412545 is interpreted as a Two Thumb advance moraine remnant. In the Two Thumb Range several small moraines near the heads of Black Birch Creek and Bush Stream are included in this formation.

c) Ice Extent. During the Two Thumb advance the Clyde and Havelock glaciers coalesced and extended about 3 km into the main Rangitata Valley terminating at about 550 m a.s.l. Small glaciers also occupied valleys in the Two Thumb Range as far south as Blind Spur Stream. The deposits of this formation occupy a similar position in the valleys as do those of the Lake Stream and Wildman formations. Thus these three formations are considered to be contemporaneous.

iv) The Springston Formation

a) Name and Distribution. The Springston Formation is formally described by Suggate (1963b). It occurs close to the Ashburton, Hinds and Rangitata Rivers along the inner plains margin (Maps 3, 4). Towards the coast this formation becomes more extensive, particularly between the Ashburton and Hinds Rivers. Alluvium and alluvial fan members are mapped (Map 8).

b) Surface Form.

1. Alluvium Member. Along the inner plains margin the Springston Formation consists of low terraces 3 m - 8 m above the present river beds. These terrace surfaces are all clearly channelled.

2. Alluvial Fan Deposit Member. Small, low alluvial fans associated with Chapmans Creek and Middle Stream in the Rangitata Valley are included in this member. They have been partly truncated and incised and are no longer active.

c) Age Relationships. Suggate (1963b) interprets the Springston Formation as being formed during the postglacial rise in sea level. This interpretation is followed here.

The time of the postglacial sea level rise covers the Early Holocene, therefore the Springston Formation was probably deposited at least in part contemporaneously with the Lake Stream, Wildman and Two Thumb formations. The deposition of these three formations is clearly related to a period of Early Holocene glacial activity. However the deposition of the Springston Formation was probably not directly related to this event and is considered to have resulted from the "rising (river) base levels during the post-glacial rise of sea level" (Suggate 1973).

3. LATE HOLOCENE DEPOSITS

Recently formed, and presently forming deposits can be seen scattered throughout the field area. No formation name is proposed for these deposits which are designated on the maps using an 'f' symbol, following the usage of the N.Z. Geological Survey maps. Six units are recognised: till, alluvium, alluvial fan, swamp, landslide and rock glacier deposits.

i) Till

Recent till is mapped near the heads of the Cameron, Ashburton and Potts rivers and in the Two Thumb and Cloudy Peaks ranges. It occurs up valley from the Early Holocene till deposits and is usually closely associated with the present day glaciers. The surface form of these deposits in the Cameron and Ashburton valleys is described by Burrows (1975). In these and other valleys very fresh, largely unvegetated moraine loops record the recent expansion of these small glaciers. The oldest of these moraines in the Cameron Valley is believed to be 4750 yrs old (Burrows 1975).

ii) Alluvium

Recent alluvium is mapped in most of the main river valleys. They include the present flood plain deposits of the rivers, and low degradational terraces generally less than 5 m above present river levels.

iii) Alluvial Fan Deposits

These are the most widespread of the recent deposits, occurring in all the main river valleys. A wide variety of alluvial fan forms are mapped, ranging from the large, low angle fans associated with Bush Stream, Forest Creek and the Potts, Cameron and Swin rivers, to small steep fans in the eroding parts of the foothill ranges. These latter would probably be more accurately described as talus deposits, however for simplicity they are mapped as alluvial fan deposits.

Alluvial fan deposits of many different ages have been mapped and described in previous chapters. Fan deposits are mapped as Recent if they showed evidence of recent or continuing sedimentation, or are not being actively eroded by the stream that had deposited them.

iv) Swamp Deposits

Recent swamp deposits are common, particularly in the intermontane basins and frequently occurring in hollows on the moraine surfaces. Numerous shallow lakes can also be seen impounded by moraines and alluvial fans, particularly in the Lake Heron and Lake Clearwater basins.

v) <u>Landslide Deposits</u>

Isolated occurrences of recent landslide deposits are mapped. Several can be seen on the slopes of the Harper Range, and others are mapped in the Ben McLeod and Two Thumb ranges and in the Lawrence Valley (Burrows, *pers. comm.*). The two largest of these landslide deposits occur in the Lake Clearwater basin (grid ref. Map 3, J36/513302, S81/588460) and in Pudding Valley (grid ref. Map 3, J36/577236, S81/657387).

vi) <u>Rock Glacier Deposits</u>

Rock glacier deposits can be seen in numerous cirques in the foothill ranges and alpine region. They occur most commonly in the Two Thumb and Big Hill ranges. It is not known which of these rock glaciers are still active and it is possible that some may not have been active since the Early Holocene. However, as the ages of all these deposits have not been determined and as most are clearly very recent, they have all been mapped together as Recent rock glacier deposits (Maps 1, 2).

PART THREE: THE MAJOR GLACIAL SEQUENCES

CHAPTER XIII

NOMENCLATURE OF MORAINES AND FLUVIOGLACIAL FEATURES ON MAPS 5-7

1. INTRODUCTION

Three 1:25,000 scale maps (Maps 5-7) have been constructed to show the geomorphic features of the three main glacial sequences in the study area. They cover the area at the head of the Rangitata Gorge (Map 5), the Lake Clearwater basin (Map 6) and the Lake Heron basin (Map 7). These maps depict the glacial and fluvioglacial landforms of the various advances and are thus different in concept from the 1:50,000 scale lithostratigraphic maps (Maps 1-4) discussed above (Chapters 7-12).

Detailed differentiation of the landforms of the Pyramid, Dogs Hill and Trinity advances has not been attempted. This is because only scattered, discontinuous remnants are preserved, and these morphologies are generally subdued and difficult to interpret. Thus, in the absence of more complete data, detailed interpretation of these advances would be rather speculative. The Pyramid, Dogs Hill and Trinity Advance landforms mapped on Maps 5-7 have been described above (Chapters 7-9). No further discussion of these advances will be presented.

Landforms of the Hakatere/Emily and Spider Lakes/Lake Heron advances are generally well preserved and can be mapped over wide areas. Precise differentiation of these landforms has been possible. This has enabled a closer study of these two sets of younger date Pleistocene advances to be carried out.

2. NOMENCLATURE OF MORAINES AND FLUVIOGLACIAL LANDFORMS

i) Introduction

Many different types of landforms attributed to valley glaciers have been identified in the literature (Flint 1971, Embleton and King 1975, Sugden and John 1976). The nomenclature of moraines has become particularly confusing, thus it is considered appropriate that the terminology used in this study be clearly defined. In general the approach here is based on the classifications of Prest (1968), Sugden and John (1976), and Boulton and Eyles (1979). However no sedimentological input could be included due to the lack of suitable exposures.

The three glacial sequences shown on Maps 5-7 were all deposited in different types of terrain. Therefore the styles and associations of landforms are slightly different in each case. This has necessitated minor differences in criteria used in mapping between the three maps. Within each map area there are also minor differences in mapping criteria between the older Hakatere/Emily advance landforms and those of the younger Spider Lakes/Lake Heron advances. The more extensive landform preservation has enabled three distinct Spider Lakes and Lake Heron advances to be identified.

The Hakatere and Emily advances were clearly multiple events, however no age differentiation can be made as the preservation of landforms of successive ice fluctuations

ii) Moraines

The commonest moraine types identified are end, lateral and ablation moraines. Small areas of fluted ground moraine and ice disintegration moraine are also shown on Map 6.

a) End Moraines. End moraines are linear features formed transverse to the direction of ice flow by active ice at the front of the glacier. In the study area they consist of semi-continuous ridges ranging from 8 m across and 2 m high to 250 m across and 30 m high. In cross-profile the ridges are usually symmetrical, with proximal and distal slopes ranging from $12^{o} - 26^{o}$. This shape is similar to the 'dump moraines' of Andrews (1975) and Boulton and Eyles (1979). Most individual end moraine ridges are too small to be mapped and they are shown using a Prominent Moraine Ridge symbol (Maps 5-7) (see Fig. 30). However in some places they are sufficiently large to be mapped to scale (see Fig. 32). On Map 7 two discontinuous belts of Emily Advance end moraines up to 1 km across are mapped, whose form differs slightly from that described above. These areas consist of hummocky ground containing varying numbers of small, semi-continuous end moraine ridges. These belts rise up to 10 m above the general level of the surrounding moraines and fluvial surfaces. Thus these are considered to be end moraine complexes formed during rapid fluctuations of the ice front instead of the more usual single moraine ridges described above.

b) Lateral Moraines. Lateral moraines are linear features formed parallel to the direction of ice flow by active ice at the margin of the glacier. They commonly merge down valley into end moraines and consist largely of belts of discontinuous, low ridges that rarely exceed 500 m in length and 2 m - 8 m in height. These ridges are generally smaller and less prominent than the end moraines.

c) Ablation Moraine. Ablation moraine is a non-linear landform consisting of extensive areas of hummocky, undulating ground with numerous closed shallow depressions as shown in Figure 24.

FIG. 24. Ablation moraine. View south-east along southern flank of the Lake Clearwater basin near Whiskey Stream.

Total relief is generally less than 10 m, and dead ice features such as deep kettle holes, are absent. It is considered to have been formed by the ablation of ice that lowered a thin layer of supraglacial till onto the subglacial surface (Price 1973, p. 211; Boulton and Eyles 1979). It is not known how thick such a supraglacial till layer may be, however the lack of obvious dead ice forms would suggest a thickness of less than 3 m (Price 1973). Some of the relief on ablation moraine areas may be partly due to an underlying lodgement till sheet.

d) Fluted Ground Moraine. Fluted ground moraine is a linear feature consisting of gently undulating ground over which run sub-parallel low ridges (Fig. 25).

FIG. 25. Fluted ground moraine behind the Spider Lakes end moraine (arrowed), Lake Clearwater basin. Ice flowed from right to left.

These ridges or flutes are up to 300 m long, 20 m across and 1.5 m high, and are oriented parallel to the direction of ice flow. It is believed to be a sub-glacial feature formed during the retreat of actively flowing ice (Aario 1977, Sudgen and John 1976). Presumably the ice would have been debris free, as any supraglacial or englacial till on the glacier would be let down as ablation moraine and obscure the flutes. This moraine type is confined to the eastern end of the Lake Clearwater basin (Map 6).

e) Ice Disintegration Moraine. Ice disintegration moraine is a non-linear landform showing a confused topography of hummocks, hollows, ridges, closed and semi-closed depressions (Fig. 26).

FIG. 26. Ice disintegration moraine. View south-west across the Spider Lakes.

Ridges may be up to 5 m high and 15 m across, and show no pattern of orientation. Relief varies markedly over short distances. In the study area this moraine type is very similar to ice disintegration features described by numerous workers (Gravenor and Kupsh 1959, Flint 1971, Sugden and John 1976, Arrio 1977, Boulton and Eyles 1979). It is interpreted as having formed by the melting of large blocks of dead ice from beneath a thick layer of supraglacial till. It is only mapped in the Lake Clearwater basin (Map 6) and occurs in a number of belts.

f) Kettle Holes. Kettle holes have only been mapped in the Lake Clearwater basin (Map 6), there being no occurrences of this form elsewhere. They consist of steep sided depressions up to 250 m across and 30 m deep, which occur in both moraines and outwash surfaces. They are considered to represent kettle holes as described by Flint (1971).

iii) Fluvioglacial Landforms

a) Outwash Surfaces. Small remnants of outwash surfaces are associated with many of the end moraines. These surfaces formed at the margin of both active ice tongues and stagnant ice bodies. Surface channelling is obvious on all of these outwash surface remnants, and some show pitting by numerous kettle holes.

b) Meltwater Channels. Meltwater channels were active at various stages during all the glacial advances. Some formed outside lateral moraines and can be traced down valley into outwash surfaces. Other channels formed during periods of ice retreat and have cut through pre-existing moraine and fluvial features. Two sided and single sided channels can be seen. The latter probably formed close to the glacier margin, with their inner side being the ice itself (Soons 1964).

CHAPTER XIV

THE GLACIAL SEQUENCE AT THE HEAD OF THE RANGITATA GORGE

1. INTRODUCTION

Glacial and fluvioglacial landforms formed during five main Late Pleistocene glacial advances are preserved at the head of the Rangitata gorge. The bulk of these were formed during the two youngest advances, the Hakatere and Spider Lakes advances of the main lobe of the Rangitata glacier. These landforms are shown on Map 5.

2. PHYSIOGRAPHIC SETTING

After passing through the Mesopotamia basin the Rangitata River becomes confined in a steep-sided valley 3.2 km wide and over 1200 m deep. It flows east-south-east for 13 km to the head of its gorge. In this area the valley broadens and the sides become lower. On the north bank the Low Hills rise 340 m above the valley floor, then give way to the southern end of the Pudding Valley basin. This is 3 km wide and its floor is approximately 120 m above the Rangitata Valley although Pudding Creek and Moorhouse Stream are incised in narrow 60 m deep gorges below the general basin floor. It extends west-north-west for 9.25 km and links the Lake Clearwater basin with the Rangitata Valley. On the south bank of the Rangitata River is the 2 km wide Whiterock

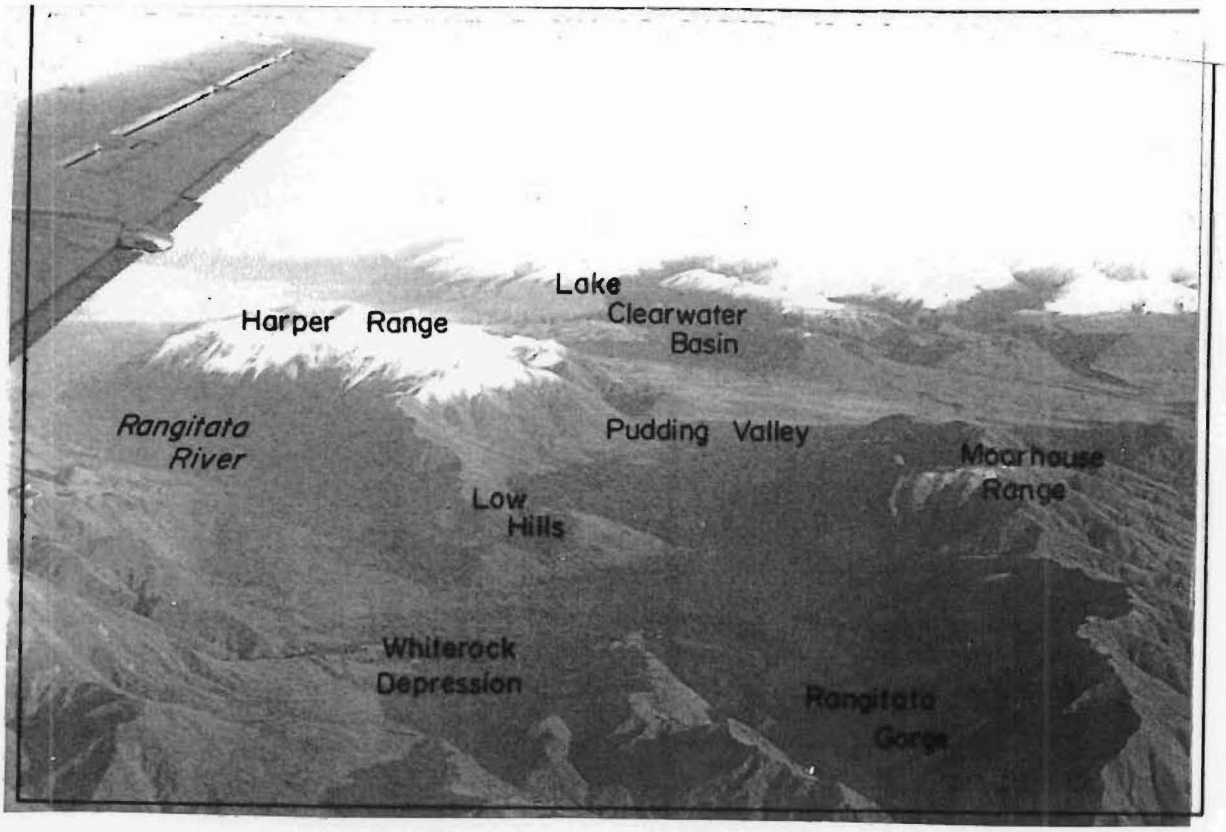


FIG. 27. Rangitata Valley at the head of the gorge.

depression. It is 165 m above the main valley and runs south-east, parallel to the Rangitata Gorge. After passing across the southern end of Pudding Valley, the Rangitata River swings to the south-east and enters the gorge (Fig. 23). This is 4.5 km long, 0.75 km wide, and issues onto the inner plains margin. The general physiographic setting at the head of the Rangitata Gorge can be seen on Figure 27.

3. THE GLACIAL SYSTEM

During the Pyramid and Dogs Hill advances, the Rangitata glacier extended through both the gorge and the Whiterock depression onto the inner margin of the plains (Fig. 6, Chapters 7, 8). However, during the three younger advances the glacier did not extend beyond the head of the gorge but was able to spread out in three small terminal lobes.

One extended northwards across the Low Hills and into Pudding Valley, a second flowed into the Whiterock depression, and the main lobe extended a short way into the gorge. The ice front reached almost the same point at the head of the gorge during all three of these advances. The latero-terminal moraine loop remnants appear to be nested inside each other through a height range of up to 300 m and across a distance generally less than 1.5 km. Thus the ice thickness apparently became less with each successive advance, although the glacier length was essentially the same each time.

Only a few scattered remnants of the Trinity advance landforms are preserved. These have been described above (Chapter 9). Morphologies of the two younger Hakatere and Spider Lakes advances are, however, much more widespread. They are preserved along the Low Hills, at the southern end of the Pudding Valley basin, and at the northern end of the Whiterock depression.

4. THE HAKATERE ADVANCES

The Hakatere advance landforms can be differentiated from the older Trinity morphologies on the basis of their slightly fresher form, and their distribution which suggests a smaller ice extent. Hakatere lateral moraines clearly cut across Trinity laterals on the Low Hills and in the Whiterock depression. At the southern end of Pudding Valley the highest Hakatere outwash surface is 45 m below the Trinity outwash surface.

The maximum extent of the Rangitata glacier during the Hakatere advance is shown on Figure 28. In the main

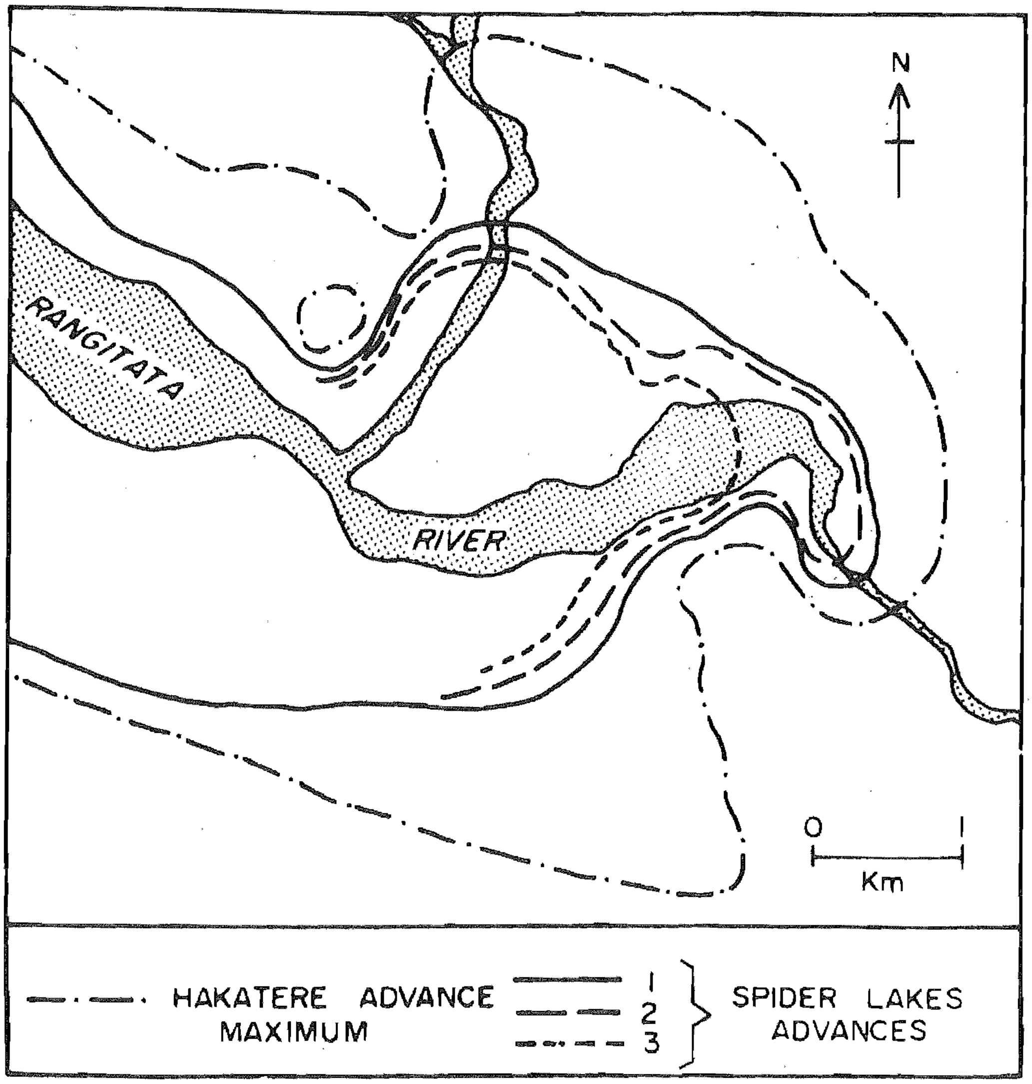


FIG. 28. Rangitata Glacier ice limits during the Hakatere and Spider Lakes advances.

valley a small moraine remnant 520 m a.s.l. at grid ref. Map 5, J36/637167, S81/719720, marks the limit of the glacier in the head of the gorge. In the Whiterock depression, two separate Hakatere advances can be recognised. The outermost Hakatere end moraine can be seen at grid ref. Map 5, J36/627148, S91/712288. The remnant, which is 563 m a.s.l., is 0.5 km long and consists of a low ridge 5 m high, littered with angular greywacke boulders up to 3 m across. Behind it is a small area of undulating ablation moraine, and in front is an outwash surface remnant. One kilometre to the west this Hakatere end moraine is somewhat larger, being 100 m across and 30 m high. It is fronted by a meltwater channel that has truncated a Trinity Advance alluvial fan. It can be followed for 1.25 km from above Coal Creek down to the Hakatere outwash surface. A second Hakatere end moraine can be seen 0.75 km to the north of the outer moraine at 558 m a.s.l. The moraine ridge can be traced westwards from grid ref. Map 5, J36/628154, S91/710297 for 1.5 km to Coal Creek. The eastern half of this ridge is less than 5 m high, however nearer Coal Creek it reaches 20 m in height. It is fronted by a 100 m wide, 15 m deep meltwater channel that can be traced eastwards onto an outwash surface in front of the smaller section of the end moraine. This outwash surface extends southwards to the outer Hakatere moraine which it cuts through at grid ref. Map 5, J36/630147, S91/713288. Here the younger outwash surface is 12 m below the older one. During these two advances meltwater from the Whiterock depression lobe of the Rangitata glacier, and drainage from Coal Creek, flowed south-east down the depression into Boundary Stream which joins the Rangitata River at the downstream end of the gorge. Subsequent advances, whilst impinging on the northern end of the depression, did not reach high enough to discharge meltwater by this route so that drainage was confined to the main Rangitata Valley. Hakatere moraines and meltwater channels can be seen on this southern bank of the Rangitata River down to 485 m a.s.l. (85 m above river level). However no further clear ice front positions can be identified.

An extensive suite of lateral moraines formed on the northern margin of the Rangitata glacier can be seen on the Low Hills. They occur between 685 m - 540 m a.s.l. Individual ridges are up to 8 m high, 15 m across, and some can be traced continuously for over 1 km. A total of eight ice front positions can be identified.

On the western bank of Pudding Stream along the base of the Low Hills, a suite of four moraines and outwash surfaces can be seen. Ranging in height between 560 m - 520 m a.s.l., they record four successive ice front positions of the small lobe of the Rangitata glacier that extended north up Pudding Valley. On the eastern bank of Pudding Creek the outwash surface remnants can be traced south-east below the Moorhouse Range into the head of the gorge. Four surfaces are preserved between 545 m - 475 m a.s.l. During the Hakatere Advance, part of the discharge from Pudding Creek consisted of meltwater from the Clearwater lobe of the Rangitata glacier (see Chapter 15). At times, this drainage was obstructed by the presence of ice in the Rangitata Valley (see Chapter 10). The outwash surfaces were presumably formed around the northern part of the Rangitata glacier terminus by meltwater from both the glacier and Pudding Valley.

It can be seen that the Hakatere advance of the main lobe of the Rangitata glacier was clearly a multiple event. However the discontinuous nature of the morphologies preserved does not enable each fluctuation of the ice front to be confidently identified and correlated from place to place. From the sequence of moraines near Pudding Valley Creek it would appear that there were at least four separate periods of ice advance that culminated in the formation of distinct outwash surfaces around the ice front. The precise position of the glacier in the main valley during these advances cannot be determined, however ice did at some stage extend about 1 km into the head of the gorge.

5. THE SPIDER LAKES ADVANCES

The Spider Lakes Advance was the youngest Late Pleistocene glacial advance to reach the area at the head of the Rangitata Gorge. The glacial and fluvioglacial landforms preserved clearly indicate that three separate advances occurred (Fig. 28). These morphologies can be distinguished from the Hakatere landforms, as they form a distinctive set at a lower level in the valley and indicate a somewhat smaller ice extent.

It is not known how much time separates the Hakatere and Spider Lakes advances. Morphologies are freshly preserved in both cases, and deposits show little weathering. Thus they were probably quite closely spaced in time. However Spider Lakes deposits can be seen at river level, so the Rangitata River had sufficient time to erode out over 60 m of Hakatere deposits from the gorge area prior to the Spider Lakes Advance.

i) Spider Lakes 1 Advance

A small area of ablation moraine at the head of the gorge (Map 5, J36/638171, S81/723313) marks the furthest extent of this advance. Flanking this moraine area is deeply channelled outwash surface at 450 m a.s.l. It can be traced for 2.5 km from grid ref. Map 5, J36/628185, S81/713332 into the head of the gorge. Remnants of it can be traced through the gorge onto the inner plains margin (Fig. 23, Chapters 11 and 17). Spider Lake 1 end moraine can be seen near both banks of Pudding Creek. It consists of low ridges generally less than 3 m high at about 470 m a.s.l. Drainage from Pudding Valley does not appear to have been able to flow around this northern margin of the glacier. Meltwater channel remnants in front of the end moraine ridge at grid ref. Map 5, J36/622189, S81/704335 slope north towards Pudding Valley. Presumably these were partly occupied by meltwater and by drainage from Moorhouse Range, which must have been able to flow back up valley around the ice front to join Pudding Valley Creek which subsequently escaped subglacially.

On the south side of Rangitata Valley below the Whiterock depression, the Spider Lakes 1 ice limit is marked by a small moraine ridge and outwash surface at grid ref. Map 5, J36/620164, S81/702306. The moraine ridge is up to 9 m high and 30 m across. Up valley from here, lateral moraines are preserved on both valley sides. However, individual ridges cannot be clearly differentiated so no attempt has been made to subdivide them.

ii) <u>Spider Lakes 2 Advance</u>

The extent of the Spider Lakes 2 Advance was almost identical to that of Spider Lakes 1. These landforms are visible close to, and below, the older features. An area of low ridges immediately behind and 30 m below the Spider Lake 1 ablation moraine marks the furthest ice extent into the gorge area. A prominent moraine ridge can be traced from near Pudding Creek south-eastwards for nearly 2 km. It is 15 m high and 50 m across, and is fronted by a number of small meltwater channels that have been incised up to 15 m below the Spider Lakes 1 outwash surface. As in the preceding advance, the ice marginal drainage along this northern part of the glacier terminus flowed north-west to join Pudding Creek and flowed subglacially from there.

On the south bank of the Rangitata River a prominent lateral moraine/meltwater channel pair can be seen inside and 10 m below the Spider Lakes 1 moraine (Map 5, J36/622167, S81/705310).

Prior to the Spider Lakes 2 advance there was probably not a long period of fluvial erosion. The glacier appears to have reoccupied much the same area as during the earlier advance.

iii) Spider Lakes 3 Advance

During this advance ice did not extend as far as the head of the gorge, terminating at about 430 m a.s.l. 1 km up valley from the two earlier Spider Lakes ice limits. A low lateral moraine ridge 3 m - 5 m high, and flanked on its outer side by a small meltwater channel, can be traced for 2 km down valley from grid ref. Map 5, J36/616163, S81/702306. It ends in an area of low hummocks from which an outwash surface can be traced a further 1 km down valley. This surface, which is 29 m above the river and approximately 45 m below the Spider Lakes 1 outwash surface, does not appear to have extended into the main part of the gorge. Lake beds have been described from beneath this lower surface (see Chapter 11, pp. 100-101. It is probable that after the Spider Lakes 2 advance, a lake became impounded behind an ice-cored moraine dam across the Rangitata Valley at the head of the gorge. This lake persisted and over 12 m of lake beds built up. It was then drained and 14.5 m of outwash gravels were deposited over the top of these lacustrine beds during the Spider Lakes 3 advance.

On the north bank of the Rangitata River, the Spider Lakes 3 outwash surface can be traced to grid ref. Map 5, J36/623181, S81/706327. From here a low moraine ridge 8 m high and 15 m across can be followed north-west for 1 km to near Pudding Creek.

The Spider Lakes 3 advance was somewhat smaller than the two previous advances. The small moraine forms and limited extent of outwash surfaces would suggest that the advance was of short duration.

6. DEGLACIAL LANDFORMS

i) Alluvial Fans

Large, low-angle alluvial fans can be seen associated with Pudding Creek and Coal Creek. Both cut through the Spider Lakes landforms and have 25 m - 20 m high, vertical front faces along the banks of the Rangitata River. They are interpreted as having been formed of reworked morainic material that was built out against the margins of the shrinking Rangitata glacier.

ii) Lake Benches

Two prominent terraces along the south bank of the Rangitata River and upstream of Coal Creek are underlain by lake beds (see Chapter 11). Similar terraces occur on the north bank and down valley from Pudding Creek. At grid ref. Map 5, J36/598165, S81/684307 the terraces are 10 m and 17 m above the river and have a clear down-valley slope. Thus they are not true lake beach levels but are probably degradational terraces cut into pre-existing lake beds, probably during the draining of the lake. The terraces are lower than the alluvial fans described above, thus are believed to be somewhat younger. It is not known whether the lacustrine sediments accumulated in a large lake that occupied the whole valley or in smaller, ice marginal lakes formed next to the retreating Rangitata glacier.

CHAPTER 15

THE GLACIAL SEQUENCE IN THE LAKE CLEARWATER BASIN

1. INTRODUCTION

The glacial and fluvioglacial landforms preserved in the Lake Clearwater basin record the five main Late Pleistocene advances of the Clearwater lobe of the Rangitata glacier. The bulk of the morphologies were formed during the final retreat of the ice. Thus a unique deglacial sequence has also been preserved. These landforms are shown on Map 6.

2. PHYSIOGRAPHIC SETTING

The Lake Clearwater basin is 20 km long, 5 km wide, and runs north-west to south-east. Its floor is 665 m a.s.l., over 860 m below the surrounding foothill ranges. At its north-western end it is continuous with, and its floor is 130 m above, the Rangitata Valley. The Potts River swings across this margin in a gorge over 100 m deep. The southern boundary is formed by the 1800 m high Harper Range, and along its northern side run the Dogs Range and Mt. Guy which rise to 1525 m a.s.l. As it is followed to the south-east, the basin becomes progressively narrower. At its north-western entrance it is 6.5 km wide, however 12 km south-east, opposite Mt. Guy, it is 4 km wide. East of here the basin expands to the north to be continuous with the Lake Heron basin to the north. The Ashburton River flows through here in front of the Clent Hills Range. Around the south-eastern margin of the basin the foothill ranges are cut by the Ashburton, Trinity and Pudding valleys that extend away south-eastwards.

Most of the basin drains south-eastwards via Lake Clearwater and Lambies Stream into the Ashburton River. However a small area of the north-western portion of the basin drains to the west into the Potts Valley. There is no major river running down the basin, thus the morphologies formed by the Clearwater lobe of the Rangitata glacier during its final retreat have been preserved largely unmodified.

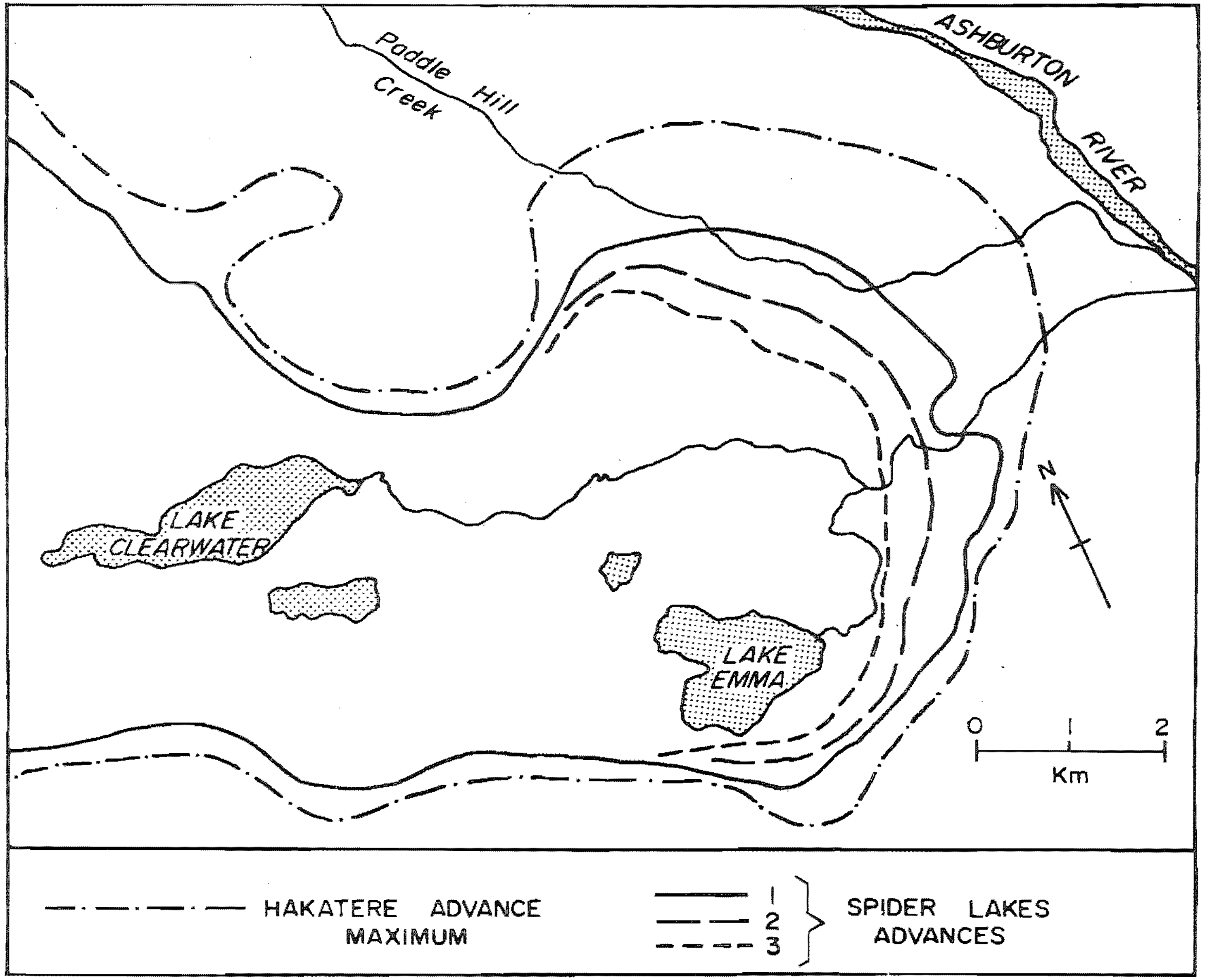
3. THE GLACIAL SYSTEM

During the Late Pleistocene glacial advances, a large distributary lobe of the Rangitata glacier (the Clearwater lobe) entered the Lake Clearwater basin (Fig. 6). This lobe became progressively narrower as it flowed south-eastwards down the basin. However, east of Mt. Guy it was able to spread out, principally north towards the Lake Heron basin and south-east down the Pudding, Trinity and Ashburton valleys. During the Pyramid, Dogs Hill and Trinity advances the ice filled the basin and coalesced with the glacier in the Lake Heron basin (Fig. 6). The evidence for these advances, which is now confined to the higher sides of the basin and on the foothill ranges, has been described above (Chapters 7, 8, 9).

During the Hakatere and Spider Lakes advances the Clearwater lobe terminated at the eastern end of the basin, as shown on Figure 29. A wide variety of glacial and fluvio-glacial morphologies formed at this time can be seen across the lower parts and around the margins of the basin.

FIG. 29.

Clearwater lobe ice limits during the Hakatere and Spider Lakes advances.



4. THE HAKATERE ADVANCES

During the Hakatere Advance the Clearwater lobe was confined to the Clearwater basin, terminating at its eastern end. Hakatere landforms are preserved here, and around the northern and southern margins of the basin (Map 6). They may be distinguished from the older Trinity morphologies by their fresher form and smaller indicated ice extent. Where seen together, Hakatere lateral moraines usually cut across the higher Trinity laterals. This can be clearly seen around the south-eastern flank of Mt. Guy.

The maximum extent of the Clearwater lobe during the Hakatere Advance is shown on Figure 29. Due to the shape of the basin the glacier surface had a rather unusual profile. From its north-western entrance for 12 km to opposite Mt. Guy the basin becomes progressively narrower. From the levels of the lateral moraines it appears that through here the ice surface sloped down gently at 13 m/km. However, east of Mt. Guy the glacier was no longer constricted and it was able to spread out and thin, sloping much more steeply at 44 m/km.

Ice entered the basin at 1100 m a.s.l. A lateral moraine complex can be traced along the flank of Dogs Range for 7.5 km. A small lobe of ice pushed nearly 2 km into the valley behind Mt. Guy, terminating at a low moraine ridge 870 m a.s.l. (grid ref. Map 6, J36/548352, S81/625516). Outwash surface remnants can be traced eastwards down this valley into Paddle Hill Creek.

Hakatere lateral moraines are also preserved on the Harper Range on the western bank of Whisky Stream.

Seven discontinuous ridges up to 300 m long, 5 m high and 30 m across occur through a height range of 1010 m - 945 m a.s.l. Around the southern flank of Mt. Guy a belt of five similar laterals can be seen between 945 m - 875 m a.s.l. (grid ref. Map 6, J36/561326, S81/639485).

The Clearwater lobe extended around the base of Mt. Guy and 3 km north towards the Lake Heron basin. A small end moraine remnant at grid ref. Map 6, J36/584343, S81/668505 marks its furthest extent here. This ridge is 745 m a.s.l. and rises 8 m above an outwash surface of limited extent, and about 18 m below the Trinity outwash surfaces (Fig. 15). Hakatere age channelling on the lower surface indicates an eastward flow of meltwater originating from the northern flank of Mt. Guy, moving into Paddle Hill Stream and then eastwards around the ice front into the Ashburton River.

On the south bank of Paddle Hill Creek, five separate terminal moraine ridge remnants are preserved (grid ref. Map 6, J36/573337, S81/654498). The innermost ridge can be traced for 1.2 km. It is 2.5 m high, 13 m wide and has 14^{o} proximal and distal slopes. The other four ridges are very similar. The outer ridge probably continues as the ridge on the north bank of the stream described above (p. 144). All these end moraines can be traced around the flank of Mt. Guy up into the lateral moraines described above (p. 144).

The eastern extent of the lobe cannot be precisely determined, however the ice margin presumably occupied a position between the outwash surface remnant at Trig P (grid ref. Map 6, J36/623317, S81/708474) and the ablation moraine at grid ref. Map 6, J36/614313, S81/697470. Here the ice front would have been at approximately 625 m a.s.l.

The south-eastern margin of the lobe is more clearly marked although evidence for multiple advances is not obvious. An end moraine ridge 20 m high and 100 m across partially blocks off the northern end of Trinity Valley. It is fronted by a small outwash surface that extends for 0.5 km south to an older Trinity moraine which entirely blocks the valley. This outwash surface consists of three surfaces separated by two small terraces (Map 6). The highest surface occupies most of the valley and extends from the end moraine. Surface channelling trends towards the south-east. The next surface is 2 m lower and is channelled to the south-east and east-south-east. The lowest surface can be seen at the north-eastern end of the valley. It is 1.5 m below the middle surface and is clearly channelled to the east and north-east. These three surfaces are probably outwash surface remnants formed during three fluctuations of the ice front. The highest surface can be related to the end moraine at the head of the valley, however the moraines associated with the two lower surfaces have not been preserved.

A belt of Hakatere ablation moraine is mapped across the eastern end of Pudding Valley. An outwash surface can be traced southwards for 2 km to the Trinity moraine in Pudding Valley. Remnants of outwash surfaces 2-3 m higher are preserved 1.75 km north of Lake Denny and are apparently related to an earlier Hakatere advance prior to that which formed the belt of ablation moraine. At this time, ice may have extended a short distance into the Pudding Valley.

A channel 0.75 km wide passes down the western side of the valley some 30 m below the Trinity outwash surface, and joins the Rangitata Valley just upstream of the gorge. Meltwater from the Clearwater lobe was able to escape down this channel during the Hakatere Advances.

It is not known how much time separated the Hakatere and Trinity advances. There are slight differences in the surface form and weathering of deposits. Clearly, sufficient time elapsed for these differences to develop. Most of the Trinity landforms were destroyed in the Clearwater basin prior to the Hakatere Advance. However there was only localised erosion of these older morphologies in the smaller valleys. Although the Hakatere Advance was clearly a multiple event, insufficient morphologies have been preserved for a more precise identification of the individual advances.

5. THE SPIDER LAKES ADVANCES

During this advance the Clearwater lobe extended through the basin to within 3 km of its eastern margin. Associated landforms are preserved inside and below the Hakatere features. They can be distinguished from the Hakatere advances largely on the basis of their smaller extent. Three separate advances can be recognised. The ice extent during these advances is shown on Figure 29.

Lateral moraines at the north-western end of the basin indicate that the Clearwater lobe here reached 1000 m a.s.l. during this advance. To the west of the Potts River an extensive suite of lateral moraines is preserved between 1000 m - 760 m a.s.l. Over 30 individual ridges can be identified. They are up to 1.5 km long, 4 m high and 30 m across. The upper ridges clearly cross-cut the higher Hakatere laterals. They have not been subdivided into the individual advances, however those below approximately 950 m a.s.l. are considered to have been formed after the last Spider Lakes advance. Similar lateral moraines can be traced along the northern margin of the basin, below Dogs Range. They can also be seen on the lower slopes of the Harper Range near Whisky Stream. None of these has been differentiated as they cannot be traced down to the individual end moraines. The ice level just reached the head of the valley that runs around the north of Mt. Guy. A small outwash surface can be traced down this valley, indicating that marginal drainage was again able to flow down here and into Paddle Hill Creek during this advance.

The configuration of these lateral features indicates that ice levels in the basin sloped from 1000 m - 850 m a.s.l. (12.5 m/km) from the entrance to opposite Mt. Guy. From Mt. Guy to the ice front, the glacier sloped more steeply from 850 m - 640 m a.s.l. (32 m/km).

At the eastern end of the Lake Clearwater basin the landforms relating to the three Spider Lakes advances may be clearly differentiated.

i) Spider Lakes 1 Advance

The easternmost extent of Spider Lakes 1 ice is marked by a small end moraine at grid ref. Map 6, J36/606313, S81/690471. The ridge, 200 m long and 4.5 m high, is at 640 m a.s.l. An outwash surface can be traced eastwards for 1.75 m nearly to the Ashburton River.

The southern margin of the ice front can be delineated by moraines near the heads of the Trinity and Pudding valleys. At grid ref. Map 6, J36/605295, S81/689450, a 3 m high moraine ridge is fronted by a small outwash surface. The moraine is 20 m below and partly butts against Hakatere moraine (p. 145). Spider Lakes 1 end moraine can also be seen across the western end of Pudding Valley. It reaches 717 m a.s.l., almost 40 m above its outwash surface that extends down the valley to Lake Denny. This surface is 2 m below the Hakatere outwash surface remnant at the eastern side of the valley.

The northern margin of the ice lobe is clearly defined by a 1 km long moraine ridge running east from the base of Mt. Guy. The ridge, which is 5 m high, 30 m across and has proximal and distal slopes of 18^{o}, is shown in Figure 30.

FIG. 30. Spider Lakes 1 end moraine ridge. Hakatere end moraine to the right. Trinity lateral moraines can be seen in the background on the lower slopes of Mt. Guy.

It is littered with sub-angular greywacke boulders up to 2 m across. The ridge can be traced around the south-eastern flank of Mt. Guy into Spider Lakes lateral moraines at 885 m a.s.l.

ii) Spider Lakes 2 Advance

Extensive remnants of the Spider Lakes 2 end moraine are preserved, particularly from around the northern and eastern margins of the glacier. A low moraine ridge can be followed for 1.5 km east from the base of Mt. Guy. Another segment of the end moraine can be seen running southwards for 1.7 km from grid ref. Map 6, J36/594316, S81/677474. This ridge has a variable shape. At its northern and southern ends, for a distance of 300 m and 500 m respectively, it is 15 m across and 2-3 m high. The central section, 900 m long, is far bulkier, being up to 200 m wide and 13 m high. A system of very small meltwater channels leads away from this moraine. They cut through the Spider Lakes 1 ablation moraine to coalesce at grid ref. Map 6, J36/605311, S81/689468 and flow in a 125 m wide 5 m deep channel that can be traced eastwards below the Spider Lakes 1 outwash surface.

From Lambies Stream south-west to Pudding Valley, only one small Spider Lakes 2 end moraine remnant is present at grid ref. Map 6, J36/593283, S81/675438. This is on the inner edge of an outwash surface that can be traced north-east for 3 km to Lambies Stream, and butts against the Spider Lakes 1 moraine at the head of Trinity Valley (p. 148). It is 10 m below the Spider Lakes 1 outwash surface, and isolated remnants can be traced down Lambies Stream to the Ashburton River. At grid ref. Map 6, J36/593278, S81/674433 a large kettle hole, 175 m across and 20 m deep, can be seen in this surface. This was probably formed by the melt-out of a large block of Spider Lakes 1 ice that had been buried by Spider Lakes 2 outwash.

A belt of ablation moraine is mapped across the end of Pudding Valley. It is deeply kettled and is 20 m below the Spider Lakes 1 moraine which it has partially overridden. This earlier moraine blocked the head of Pudding Valley, thus forcing meltwater to flow north-east around the ice front into the Ashburton River.

iii) Spider Lakes 3 Advance

The morphologies of this, the youngest Late Pleistocene advance of the Clearwater lobe, are remarkably well preserved at the eastern end of the Clearwater basin. The ice front that extended from Mt. Guy across to the entrance of Pudding Valley was 9.25 km long. Of the ice contact features that were formed along this ice margin, only 1.75 km have been subsequently removed. This landform pattern is shown on Figure 31.

An end moraine was deposited around the northern and eastern part of the ice front. In parts, this moraine is very variable in size.

The northern ice margin is marked by a small moraine ridge 2 m high and 10 m across, that can be traced eastwards from the base of Mt. Guy for nearly 1.5 km to the Spider Lakes. This ridge is fronted by several small meltwater channels that drained into a slightly larger channel 90 m wide and 6 m deep. This can be traced north-east away from

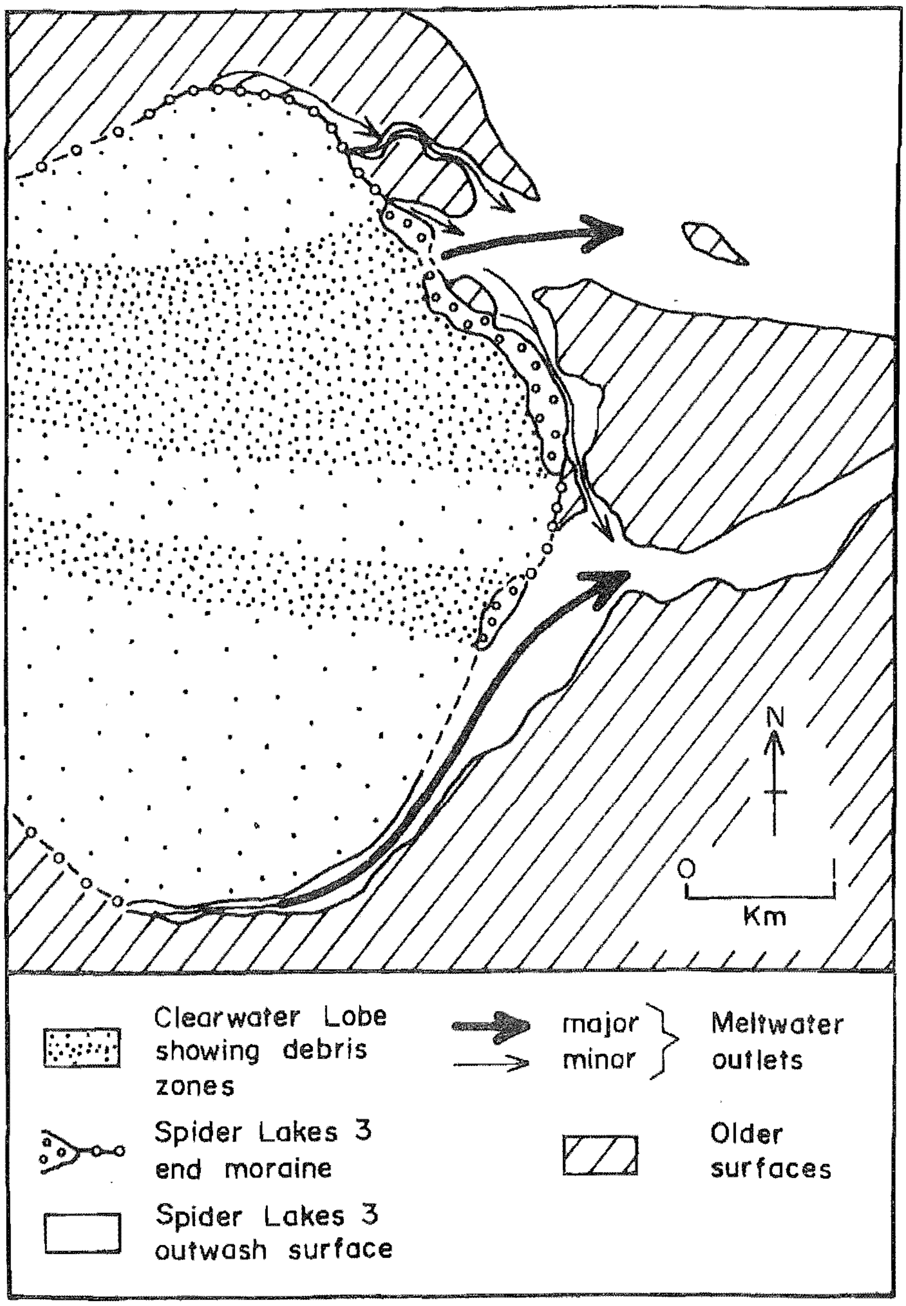


FIG. 31. Spider Lakes 3 Advance ice contact landform pattern.

the ice front and into Paddle Hill Creek (Map 6, J36/578323, S81/660484). A similar channel can be seen 0.5 km to the south. Both these channel systems are cut through a fluted ground moraine surface formed during the retreat of Spider Lakes 2 ice. From the area of Spider Lakes, south-east for 2.1 km, the end moraine is much larger, up to 20 m high and 200 m across, with 22^{o} proximal and distal slopes (see Fig.

FIG. 32. Part of the Spider Lakes 3 Advance end moraine ridge.

32). At grid ref. Map 6, J36/586318, S81/665478 the ridge is cut by a 175 m wide meltwater channel. This opens out onto an outwash surface remnant that can be traced north-east towards Paddle Hill Creek. Meltwater from this channel also flowed south-east in a channel in front of the moraine to join Lambies Stream. In this latter meltwater channel is a kettle hole 30 m wide and 6 m deep at grid ref. J36/597307, S81/679464. The Spider Lakes 3 moraine diminishes abruptly in size to a small ridge (Map 6, J36/592305, S81/678461) similar to that described above, and continues as a ridge 2 m high for 350 m to Lambies Stream (see Fig. 25). On the south bank of this stream the Spider Lakes 3 moraine is again much larger. This remnant is fronted by an outwash surface that can be traced south-west to the western side of the entrance to Pudding Valley. No end moraine remnants can be seen around this south-eastern side of the former ice front. It is probable that meltwater activity here did not allow a moraine ridge to form. The outwash surface is 6 m below the Spider Lakes 2 outwash surface and 8 m above Lambies Stream. Surface channelling indicates that meltwater was flowing north-eastwards. No channelling is aligned with the present course of Lambies Stream where it cuts through the moraine loop. Thus it is probable that the present stream channel became established after the Spider Lakes 3 advance.

From these landforms a picture may be built up of the nature of the glacier and the ice front depositional environments. The variation in the size of the end moraine is believed to reflect variations in the supraglacial debris load. The moraine loop is symmetrical in cross-profile, thus it may be interpreted as a dump moraine formed at the stationary margin of the actively flowing Clearwater lobe by the avalanching of supraglacial debris from off the ice surface (Andrews 1975). The low part of the end moraine would have been formed in front of relatively clean, debris-free ice, and the bulky part of the moraine in front of heavily debris-laden ice (see Fig. 31). There appear to have been two zones of debris, probably medial moraines, on the middle of the glacier. These medial moraines could have been derived from the junction of the Clyde and Lawrence glaciers 34 km up valley (Fig. 6). Around the northern margin of the Clearwater lobe there were only localised zones of meltwater discharge. However, large amounts of meltwater issued from the southern margin of the lobe to form an outwash surface.

Summary of the Spider Lakes Advance

The Spider Lakes advance was the youngest Late Pleistocene advance of the Clearwater lobe. It is not known how much time separates the Hakatere and Spider Lakes advances. Both sets of morphologies show very little post-depositional modification. However, sufficient time did elapse for most of the Hakatere landforms in the Lake Clearwater basin to be removed prior to the Spider Lakes advance.

Three Spider Lakes advances can be recognised. Kettle holes in the Spider Lakes 2 and 3 outwash surfaces indicate that dead ice from the preceding advances was still in existence at the time these outwash surfaces were forming. Thus these advances were probably quite closely spaced.

6. DEGLACIAL LANDFORMS

Most of the landforms in the lower parts of the Lake Clearwater basin were formed as the ice lobe retreated after the Spider Lakes 3 advance. A variety of glacial and fluvioglacial landform associations are preserved that allow a detailed reconstruction of the pattern of ice retreat to be determined. Features preserved include active and dead-ice morainic forms and various fluvial surfaces. These have been described above (Chapter 13). Nine ice form lines can be recognised that represent successive positions of the ice front as it retreated from the basin. The pattern of deglaciation appears to have been affected by the nature of the supraglacial debris load. From the variation in the size of the Spider Lakes 3 end moraine, it was suggested above (p. 153) that there were two zones of debris extending down the middle of the Clearwater lobe. These zones were flanked on either side by areas of relatively clean ice. As the glacier retreated, the more debris laden zones stagnated whilst the cleaner ice to either side retreated more rapidly.

i) The Deglacial Sequence

Nine ice formlines are identified by a variety of landform associations that formed around the terminal zone of the glacier. Figures 33 and 34 show the positions and profiles of these ice formlines. Various landforms developed at different parts of the ice front, depending on the nature of the glacier behaviour. During the initial stages of retreat the debris free zones on the northern and southern margins of the glacier retreated, exposing areas of fluted ground moraine. These can be seen between the Spider Lakes and the base of Mt. Guy, on the north bank of Lambies Stream (Fig. 25) and around the northern and southern shores of Lake Emma. These are the only areas of fluted ground moraine that have been identified in the basin. It is not known why subsequent retreat of the ice front did not expose any more of this moraine type. This may merely reflect a lack of preservation due to subsequent removal or it may reflect an overall change in the behaviour of the ice in the terminal zone. Fluted ground moraine is believed to be an active-ice form (Aario 1977). Thus if the ice front stagnated, these

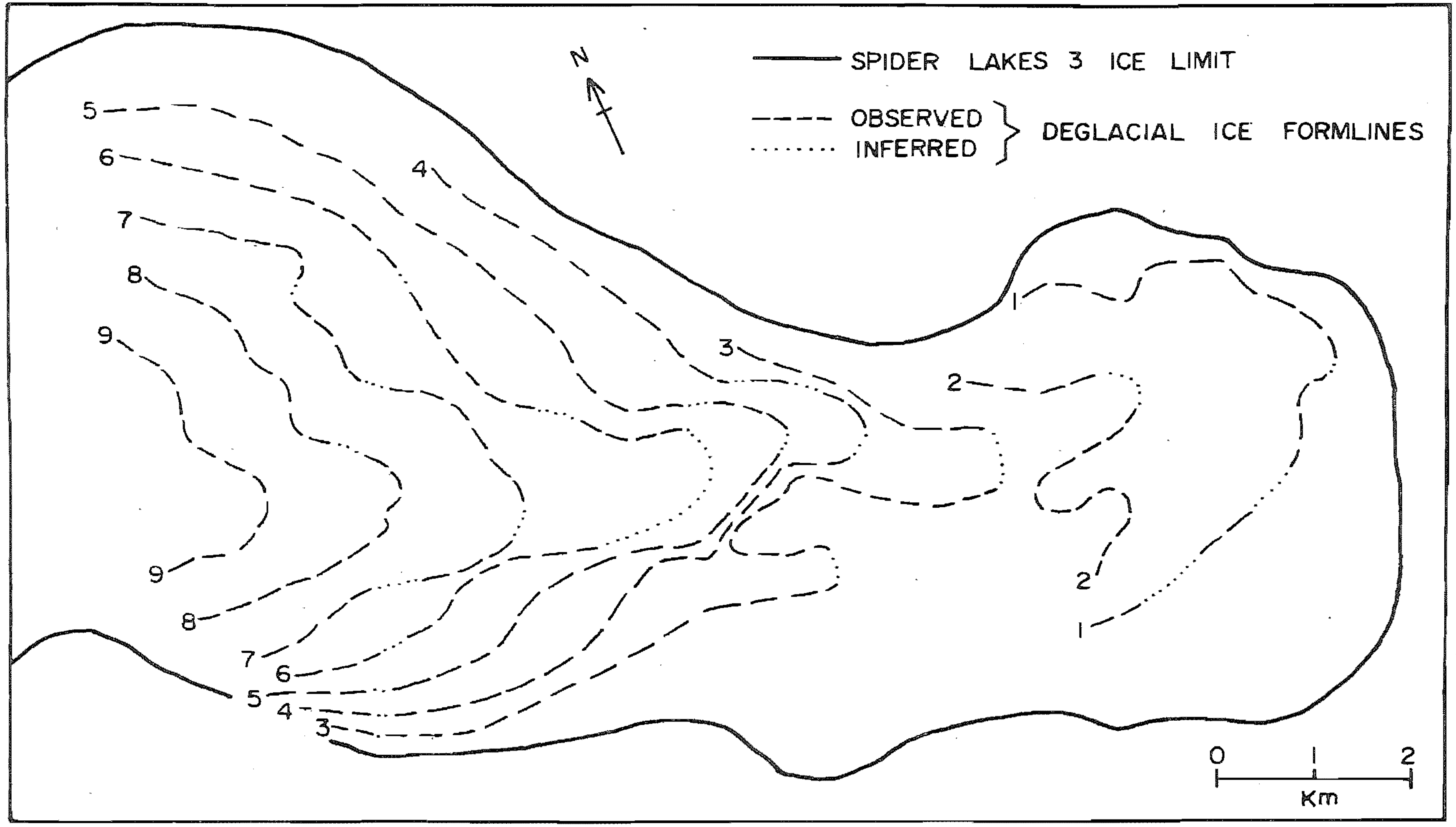


FIG. 33. Deglacial ice formlines in the Lake Clearwater basin.

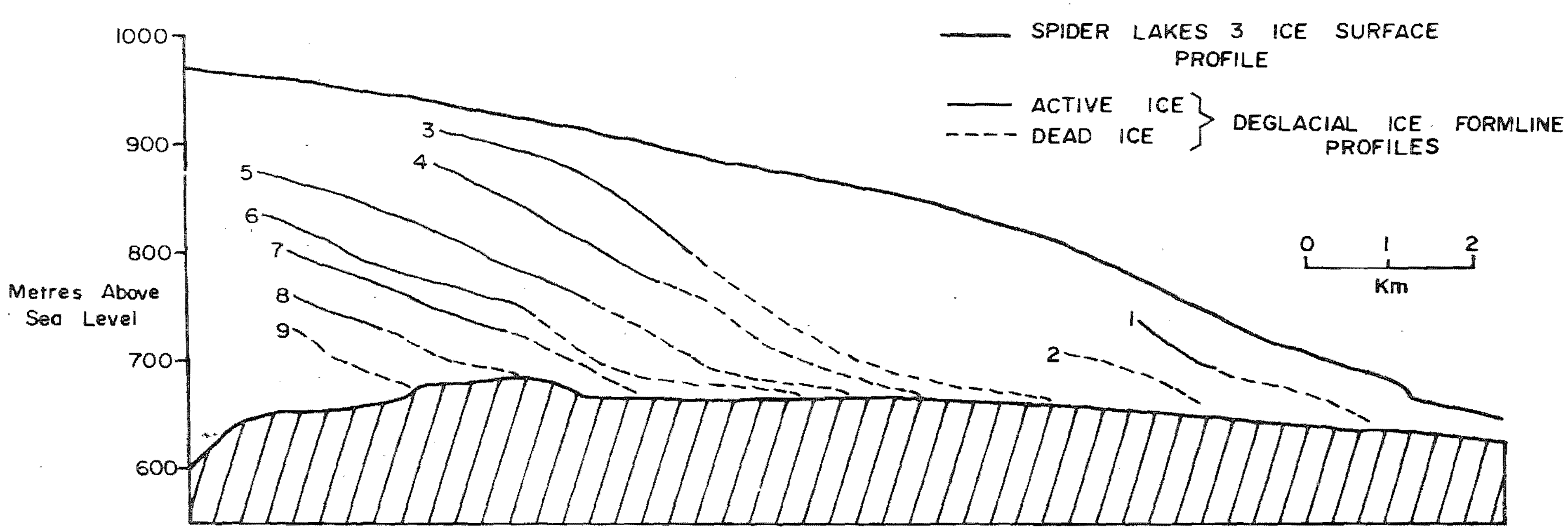


FIG. 34. Profiles of deglacial ice formlines in the Lake Clearwater basin.

forms could not develop. This latter explanation is favoured here.

The central zone of the ice front, behind the larger parts of the end moraine, did not actively retreat. The ice stagnated beneath its thick debris cover, and downwasted to form an area of ice disintegration moraine (see Fig. 26). It is possible that this ice body became separated from the rest of the glacier. At this time meltwater escaped into Paddle Hill Creek through the moraine loop near the Spider Lakes (see below), and also passed south-eastwards immediately behind the moraine ridge into Lambies Stream.

Ice formline 1 is marked by a small moraine ridge at the base of Mt. Guy. This is an active ice form and it is fronted by fluted ground moraine. This indicates that the ice front here had retreated steadily for 0.8 km from the Spider Lakes 3 end moraine, exposing the fluted ground moraine. The retreat then halted and a small moraine ridge formed at this now stationary margin of the still actively flowing glacier. The moraine ridge can be followed south-eastwards to the Spider Lakes where it passes into the area of disintegration moraine described above (p. 158). Ice formlines on the southern side of the basin between Lakes Emma and Camp are not visible due to the large recent alluvial fan of Balmacaan Stream and the extensive swamp between it and Lake Emma.

From this evidence the initial pattern of ice retreat can be established. In response to the ameliorating climate the glacier mass budget became negative and the ice front began to retreat. The glacier terminus was still active, although debris laden areas of ice across the middle of the glacier stagnated and probably became detached from the main ice lobe.

As the retreat continued, a series of six small moraine ridges were formed behind ice formline 1 around the base of Mt. Guy (Map 6, J36/560318, S81/640478). Two are fronted by small outwash surfaces. These ridges represent brief still stands during retreat. However they are of localised extent and are not considered to represent major ice formlines. They indicate that this part of the terminal zone of the glacier continued to be active during this retreat phase.

Ice formline 2 is 1.5 km west of formline one and is marked by an arcuate belt of disintegration moraine fronted by a kettled outwash surface. The ice front consisted of two stagnating lobes, marked by a disintegration moraine belt around Lake Roundabout which can be followed around a higher slightly older mound of ablation moraine to a similar belt 1.25 km to the north. Clearly the two debris zones on the glacier surface were affecting the pattern of ice retreat so that two lobes of stagnant ice developed at the glacier terminus. The outwash surface in front of the disintegration moraine belt extends eastwards for 1 km. It can also be followed back around the ice front for 1.25 km to the base of Mt. Guy. In this area there are no moraine ridges in the ablation moraine, so if the glacier was still actively flowing here, the ice front was retreating continuously.

During the subsequent phases of deglaciation the glacier was retreating through the progressively broadening part of the Clearwater basin. Thus the ice front became longer and the ice formlines can be traced over greater distances. Meltwater activity became more confined to the northern parts of the ice margin where eight deep meltwater channels have been incised into the ablation moraine surfaces (see Map 6 north of Lake Clearwater). These channels can be traced back to the gorge of the Potts River (see below). However, along the steeper Harper Range margin of the Clearwater lobe, moraines continued to form. The lower limit of Spider Lakes advance lateral moraines is here mapped at about 920 m a.s.l. Below this is an area of deglacial lateral moraines extending down to 820 m a.s.l. These moraine ridges, which are low and generally less than 0.5 km long, pass into a large area of ablation moraine below about 760 m a.s.l. This area is shown in Figure 24 (p. 124).

Ice formline 3 is marked by the prominent belt of disintegration moraine that flanks the stream draining Lake Clearwater. It is fronted by an outwash apron and a meltwater channel system along the base of Mt. Guy. At this time a small lobe of ice also sat in the area now occupied by Lake Camp. Thus the two zones of supraglacial debris appear to have still been influencing the pattern of ice retreat. The southern margin of the glacier is marked by a meltwater channel which can be traced around the side of Lake Camp and westwards along the lower Flank of the Harper Range for 2 km to where it disappears beneath the surface of a recent landslide. Continuing the trend of this meltwater channel, the ice formline passes into lateral moraines 0.6 km to the west. The change from active to stagnant ice forms here, suggests that at the time the ice was at formline 3 the lower

4.5 km of the glacier had become stagnant (Fig. 34).

Ice formline 4 can be identified from a belt of disintegration moraine and associated meltwater channels around the south-eastern end of Lake Clearwater. A 25 m deep meltwater channel can be traced from near the lake for 3.5 km north around the base of Mt. Guy. This is the left channel in the left middle ground of Figure 35. On the southern shore of Lake Clearwater an outwash surface remnant at grid ref. Map 6, J36/535315, S81/611475 is 12 m below the outwash of ice formline 3. Small remnants of the surface can also be seen for 1.5 km down valley inside the belt of older disintegration moraine. At the lake outlet, the lower parts

FIG. 35. Meltwater channels incised into an ablation surface near the eastern end of Lake Clearwater.

of the disintegration moraine belt are considered to have formed at this time. Prominent moraine ridges on the northern and southern ice margins (Map 6, J36/527339, S81/604500; J36/513314, S81/588473) mark the limit of active ice in the basin, the lower 3 km of the Clearwater lobe being stagnant. The bilobate patter of ice formlines 2 and 3 had not persisted. Continued lowering of the ice surface had probably enabled supraglacial streams to rework and combine the two previously discrete debris zones.

Ice formline 5 is marked by a meltwater channel system that can be traced from near the Potts River (grid ref. Map 6, J36/484377, S81/560543) south-east for 11 km to near the eastern end of Lake Clearwater. At this time, the second of the eight major meltwater channels that open out onto the floor of the basin at grid ref. Map 6, J36/528326, S81/605486 was active (channel in right middle ground of Fig. 35). Meltwater discharged from here around the ice front which sat near the present outlet of Lake Clearwater. This ice formline is marked along the Harper Range by a small meltwater channel that swings away from the shore of Lake Clearwater (grid ref. Map 6, J36/519316, S81/595475) towards Whisky Stream (grid ref. Map 6, J36/498312, S81/572471). The formline then passes into an area of low lateral moraine ridges that extend 0.7 km to the west of Whisky Stream. During this phase of the deglaciation the lower 3 km of the ice lobe had stagnated. The ice front had retreated 6.5 km from the Spider Lakes 3 end moraine, and the glacier surface had been lowered by 100 m at the entrance to the basin (Fig. 34).

Ice formline 6 is marked by the intake of a narrow meltwater channel on the southern shore of Lake Clearwater that can be followed through the ablation moraine to Whisky Stream. The northern ice margin is also marked by a meltwater channel. It can be traced from near the Potts River (grid ref. Map 6, J36/486373, S81/560538) south-east to near Lake Clearwater. From grid refs Map 6, J36/506352, S81/581518 to J36/508341, S81/583507, several small moraine ridges are mapped along the ice formline. The meltwater channel here swings 0.75 km away from the ice front for 2.4 km, rejoining it where the channel issues out into the floor of the basin (Map 6, J36/516333, S81/592494). This part of the channel is now occupied by Kenneth Creek.

Ice formline 7 is identified by the prominent belt of disintegration moraine that extends across the floor of the basin near the western end of Lake Clearwater. As the ice front stagnated here, meltwater flowing around the northern margin of the glacier built up two outwash fans that extend from the Kenneth Creek meltwater channel, and that 0.75 km to the west at grid ref. Map 6, J36/509333, S81/584494. These outwash fans have three closely spaced levels and they have been formed some 60 m below the level of the main ablation moraine surfaces. At their southern edges, these outwash fans are approximately 15 m above the lake. An undulating ablation moraine surface extends for 90 m from here down to the lake shore. Thus it appears that these fans were built out against a large, dead ice body that occupied most of the area of the present Lake Clearwater.

Ice formline 8 is marked by a disintegration moraine belt 1.2 km west of formline 7. It is fronted by an outwash fan that can be traced from the Craddock Stream meltwater channel and another 0.5 km to the west at grid ref. Map 6, J36/494338, S81/568500. Ablation moraine at the lake shore across the end of this fan indicates that dead ice still occupied parts of the Lake Clearwater area.

Ice formline 9 is marked by two disintegration moraine belts above the Potts River (grid ref. Map 6, J36/478356, S81/551520) and across the floor of the basin (grid ref. Map 6, J36/486336, S81/559498). Here it is fronted by a kettled outwash surface that extends 300 m north-west into two large meltwater channels. These can be traced back 0.2 km to above the Potts River. No active ice features are preserved around the formline, thus it is probable that this last remnant of the Clearwater lobe had become stagnant. At this stage the ice front had retreated 11.5 km from Spider Lakes 3 end moraines. The ice surface had been lowered by 230 m and active ice had ceased flowing into the Lake Clearwater basin. After the ice had downwasted below ice formline 9, the Potts River was no longer able to drain into the Clearwater basin and it was forced to form a new course into the Rangitata Valley.

ii) Summary of the Deglacial Sequence

At the end of the Spider Lakes Advance regional snowlines rose, and in response the Rangitata glacier thinned and its various ice fronts began to retreat. Initially, parts of the Clearwater lobe ice front remained active. However the central parts of this lobe became stagnant under a thick insulating debris cover. By the time the lobe had retreated to ice formline 2 the whole ice front had begun to stagnate. The lateral ice zones, being somewhat less debris laden, retreated more rapidly than the central ice zone. During the second and third ice formline phases, two discrete lobes of stagnant ice developed, presumably beneath two different medial moraines. However, subsequent formlines do not show this bilobate pattern. The lower eastern parts of the ice formlines represent places of stagnation of the ice front. At no stage during the deglaciation is there any evidence for a re-advance of the glacier. Ice continued to flow into the basin from the main glacier. However this was insufficient to nourish the whole Clearwater lobe, so after the initial retreat to ice formline 1, the lowermost 1.5 km - 4.5 km of the glacier was always stagnant. The whole glacier surface was lowered as the ice front progressively stagnated. This situation of a retreating glacier continuing to flow behind a large area of dead ice resembles the present day Tasman Glacier 70 km south-west from here. This glacier has, since the early 20th century, been in a negative mass balance (Goldthwait and McKellar 1962, Skinner 1964). At present the lower 9 km has stagnated and is slowly down-wasting beneath a thick supraglacial debris cover.

During the Spider Lakes 3 Advance, the surface slope of the Clearwater lobe averaged 20 m/km. However the slope of the active part of the lobe became steeper during the deglaciation, ranging between 30-40 m/km. In contrast, the lower, inactive part of the lobe tended to have a much gentler slope, at times as low as 10 m/km.

Through the north-western sector of the Lake Clearwater basin the northern margin of the ice front was able to retreat further than on its southern margin (Fig. 33). The cross-basin profile is here asymmetrical, the southern Harper Range side being steeper than the northern side. Ice in this latter area was some 100 m thinner than at the basin axis. This, and a thinner debris cover, allowed the ice to melt back further here during each retreat phase.

The presence of some lateral moraine areas along the northern and southern margins of the basin suggest that there were periods of still stand during retreat of the active part of the Clearwater lobe. Therefore the ice formlines, while not indicating actual readvances, may represent brief pauses during the overall deglaciation. Thus it is probable that the general rise in regional snowline was not continuous but occurred in numerous small steps. It is also clear that the rise of the snowline occurred at such a rate that almost the whole glacier was able to remain active, and only a relatively small part of the ice front stagnated during the retreat.

It is not known how these ice formlines of the Clearwater lobe were related to the retreat of the main lobe of the Rangitata glacier. During the period when ice occupied formline 9, active ice in the main Rangitata Valley was probably at about 750 m a.s.l. Projecting this level down valley at 30 m/km the ice front would have been near Forest Creek, and the ice margin in the Mesopotamia basin at the level of the moraine ridges described in Chapter 11.

iii) Other Deglacial Landforms

a) The Paddle Hill Creek Surface. This is the largest fluvial surface shown on Map 6. It is a fan shaped feature extending from an apex at 820 m a.s.l. north of Mt. Guy, for 7.6 km to the Ashburton River where it is 2.5 km wide and 610 m a.s.l. The surface has been vertically displaced approximately 35 m by the Lake Heron fault (see Appendix 2).

The surface is deeply channelled, and littered with large subrounded greywacke boulders up to 1 m across. It is interpreted as a degradational surface formed mainly by Paddle Hill Creek and partly by the small stream that drains from the Spider Lakes.

Interpretation of the age of this surface is problematic. Along its northern margin it is incised 40-15 m below Trinity and Hakatere surfaces, and is therefore somewhat younger than these advances here. On its southern side the surface is incised 15-8 m below Trinity, Hakatere and Spider Lakes surfaces. The deglacial meltwater channel that passes through the Spider Lakes 3 moraine ridge near the Spider Lakes merges with the Paddle Hill Creek surface at grid ref. Map 6, J36/593320, S81/674479. Thus along this southern margin the surface was probably formed during the early phases of deglaciation. The size of the surface is anomalously large in relation to the present size of Paddle Hill Creek. It is difficult to see how such a large feature could be formed by the Creek during a single phase of downcutting. During the glacial advances the Creek's discharge was augmented by meltwater flowing between the Clearwater lobe and the Dogs Range, into its catchment via the valley to the north of

Mt. Guy. However these meltwater channels are very small and this extra water probably did not greatly increase the discharge of the Creek. The Paddle Hill Creek surface has therefore probably been formed over a longer period, with its age decreasing laterally from north to south. Along its southern margin it is clearly younger than the Spider Lakes advances. The whole surface is thus mapped as a deglacial landform, however parts of it presumably formed earlier during the Spider Lakes advances.

b) The Potts River Gorge. A striking feature of the landscape at the western end of the Clearwater basin is the Potts River gorge. It is 0.75 km wide and is incised 100-250 m below the general level of the basin floor. The Potts River drains into the Rangitata Valley, however during the Late Pleistocene the Clearwater lobe extended across the present course of the river. Meltwater channels in the north-western part of the Clearwater basin can be traced to the gorge, indicating that the Potts River discharged through this basin and into the Ashburton Valley. These meltwater channels do not appear to be large enough to accommodate the present Potts River. It is thus possible that the river was able to partly drain subglacially, although it is not known whether this then entered the Rangitata Valley or the Clearwater basin. From the arrangement of meltwater channels described above, it can be seen that part of the Potts River drainage was forced to escape through the Clearwater basin until the Clearwater lobe finally retreated out of the basin. The present gorge is thus a postglacial feature, although part of it may have been cut subglacially during the Spider Lakes advances.

CHAPTER 16

THE GLACIAL SEQUENCE IN THE LAKE HERON BASIN

1. INTRODUCTION

During the Late Pleistocene the Lake Heron basin was occupied by a large distributary lobe of the Rakaia glacier, which coalesced with the smaller Cameron Glacier. Landforms of the five main Late Pleistocene glacial advances have been preserved (Map 7). By far the bulk of these were formed during the two youngest Emily and Lake Heron advances.

2. PHYSIOGRAPHIC SETTING

The Lake Heron basin is 25 km long, 8 km wide and runs north-south. Its floor is 690 m a.s.l., over 1200 m below the surrounding foothill ranges. At its northern end it is joined with the Rakaia Valley by the 8 km long, 1.3 km wide, downstream section of the Lake Stream Valley. Here the basin is 3 km wide. The maximum basin width of 9.6 km occurs 4 km south of the lake. A further 2.4 km to the south the basin is abruptly narrowed to 5.2 km by the 1300 m high Clent Hills Range. The 1.3 km wide Stour Valley leads away to the south-east around the eastern flank of this range. At its southern end the Lake Heron basin is continuous with the Lake Clear-water basin.

The northern half of the basin drains northwards via Lake Stream into the Rakaia River. The Swin River, Lake Heron and Cameron River all feed into this drainage system. The southern half of the basin drains southwards. There is no major river here, with the drainage lines being often swampy and poorly developed. Most of the small streams join Gentleman Smith Stream that flows into the Ashburton River via the Maori Lakes. The lack of a major river in this southern half of the basin has resulted in the preservation of a wide variety of glacial and fluvioglacial landforms across the floor of the basin.

A number of elongate hard-rock ridges rise above the basin floor along its eastern side. They are Isolated Hill, Rikki Spur, Longman Range, Emily Hill and Mt. Sugar Loaf. All are aligned north-south, and range from 2 km - 4 km long by 0.6 km - 1.2 km wide, and are between 150 m - 250 m above the basin floor. The largest is Mt. Sugarloaf, rising 542 m above the eastern shores of Lake Heron (see Fig. 37). All of these were at some stages covered by ice. During the Emily and Lake Heron advances Mt. Sugarloaf protruded above the glacier surface as a prominent nunatak.

3. THE GLACIAL SYSTEM

The Rakaia distributary lobe flowed into the Lake Heron basin up the Lake Stream Valley. Sixteen kilometres after leaving the Rakaia glacier, this lobe was joined at its western margin by the much smaller Cameron Glacier. During the Pyramid, Dogs Hill and Trinity advances this combined glacier extended right through the basin and coalesced with the Lake Clearwater lobe (Fig. 6). The evidence for these advances, which is now largely confined to the higher sides of the basin and on the foothill ranges, has been discussed (Chapters 7, 8 and 9).

During the Emily and Lake Heron advances the lobe reached into the southern half of the basin (Fig. 36). A wide variety of glacial and fluvioglacial morphologies formed at this time can be seen across the floor and on the lower margins of the basin.

4. THE EMILY ADVANCES

Most of the morphologies in the southern part of the basin were formed during the Emily advances. They may be distinguished from the older Trinity landforms by their slightly fresher surface form and the smaller indicated ice extent during the Emily advances. At their southernmost extent in the basin, near the Ashburton River, Emily landforms clearly overtop parts of some Trinity moraine forms. Younger latero-terminal moraine cuts across older laterals, and the fresher topography of the Emily moraine is clearly marked (see Fig. 7).

An informal separation into early and late Emily advances can be made.

i) The Early Emily Advances

During these advances ice reached to within 1 km of the Ashburton River. Along the eastern margin of the basin it covered Isolated Hill and almost completely surrounded Rikki

Spur. Ice was able to spread laterally into four small lobes between these hard-rock ridges. The northern lobe pushed past the north end of Longman Range 1.5 km up the Swin Valley. A lobe also extended for 2 km between Rikki Spur and Longman Range. This almost joined the lobe that flowed past the southern ends of these two ridges for nearly 1 km towards Manuka Lake. The southern lobe extended for 3 km between the Clent Hills Range and Emily Hill.

The Rakaia lobe and Cameron glaciers coalesced at about 1060 m a.s.l. Emily lateral moraines can be traced south from here for 8 km to grid ref. Map 7, J35/600408, S81/683570. They consist of numerous, discontinuous, low ridges up to 8 m high and 15 m across. In places, up to 10 individual ridges can be seen through a height range of 150 m. Presumably most of the lower ridges here were formed during the later Emily advances. The outer early Emily Advance moraine ridge can be traced for 2.75 km south-east from grid ref. Map 7, J36/594375, S81/678538 to near the Maori Lakes. Over most of its length it is quite small, being up to 5 m high and 15 m across. However the 0.75 km portion nearest Maori Lakes is 14 m high and 120 m across. It is 645 m a.s.l. Butting against the outer side of the moraine is an outwash fan probably formed contemporaneously by the Ashburton River. Remnants of three other low ridges can be seen in the ablation moraine behind this outer terminal moraine. Discontinuous, low lateral moraine ridges can be traced around the northern flank of the Clent Hills Range to near Lake Emily. Here they pass into a prominent end moraine belt at 750 m a.s.l. This 0.5 km wide belt rises some 15 m above its outwash surface, and contains

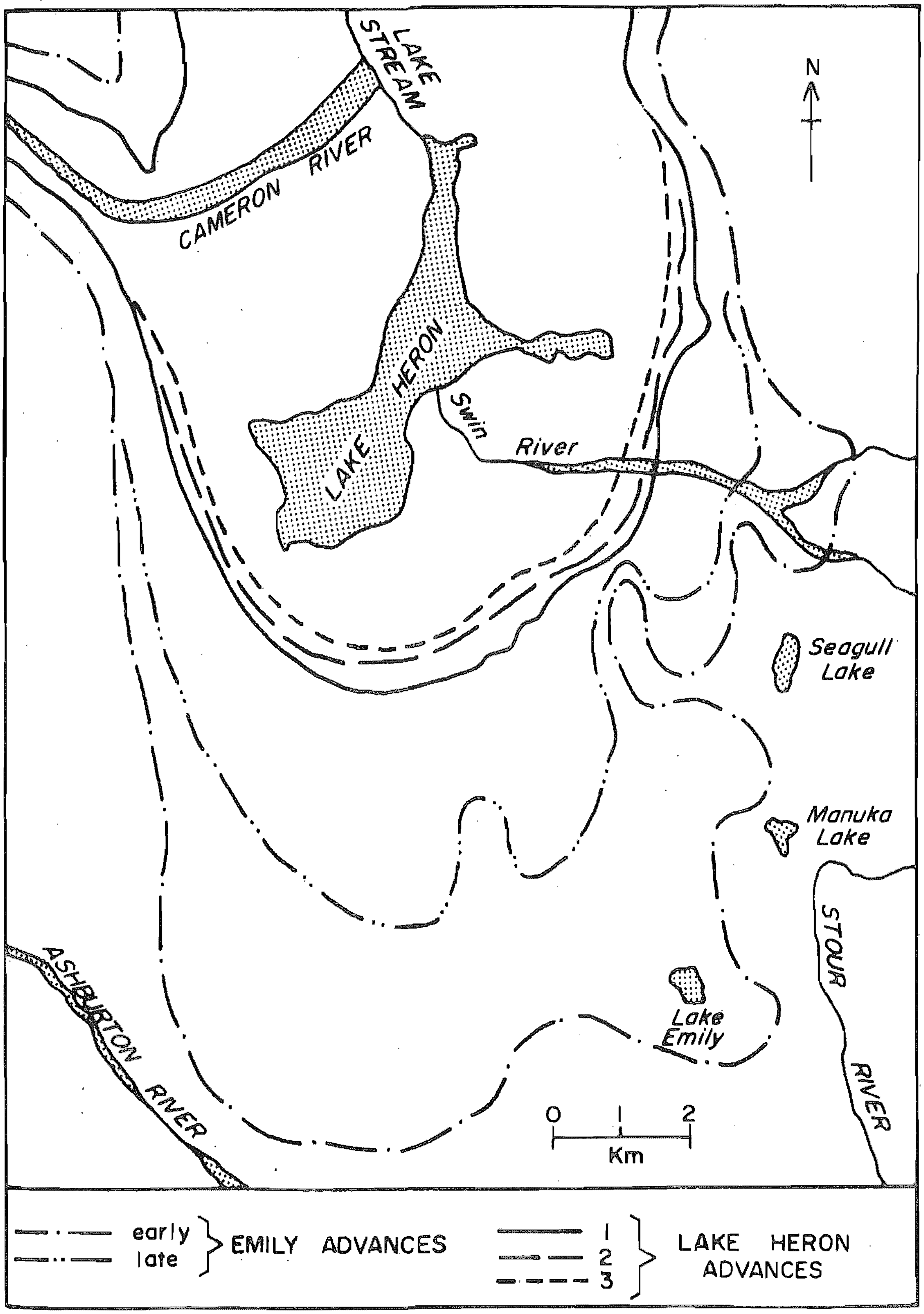


FIG. 36. Rakaia lobe ice limits during the Emily and Lake Heron advances.

three moraine ridges up to 8 m high and 20 m across. The outwash surface extends for 1.2 km south-east into the Stour Valley. A 25 m deep meltwater channel has been incised into it. This begins in the ablation moraine about 40 m above Lake Emily (Map 7, J36/672378, S81/763488) where it is 200 m wide. As it passes through the end moraine belt it broadens to 0.5 km wide. It was probably formed shortly after the early Emily advances while the ice passed during retreat allowing meltwater to escape down to the Stour Valley. A relatively flat area 30 m below, and extending for 220 m behind the end moraine belt, is also traversed by the meltwater channel. It is possibly in part a lake bench, thus the channel may have been formed by the draining of a small pro-glacial lake.

The southern end of the area between Rikki Spur and Longman Range is blocked by a broad belt of end moraine. This includes numerous ridges up to 10 m high, 40 m across and 440 m long. At 0.3 km to the north, a belt of ablation moraine is formed by the lobe of ice that had extended down this small valley. An outwash surface extends from here southwards between Longman Range and the end moraine belt. This drainage probably joined the Stour River and flowed to the east of Emily Hill, but evidence of this is obscured by recent alluvial fan formation from Finger Stream and the Stour River.

As the Rakaia lobe retreated after the early Emily advances, large areas of ablation moraine were formed across the eastern floor of the basin. Some areas of this ablation moraine also remain in the western parts of the basin.

The end moraines formed during the early Emily advances are different in character in the eastern and western parts of the basin. Numerous prominent end moraine features developed around the eastern ice margin in contrast to the limited extent of those on its western side. This suggests that the eastern part of the ice front fluctuated about its maximum extent for rather longer than the western side. These differences in the behaviour of the ice front may reflect topographically controlled variations in flow regime, or differences in the mass balance of the glacier. In the former instance, the greater thickness of ice in the western part of the basin should have promoted greater stability of the ice front and as a result, larger end moraine forms. This is clearly not the case. The second possibility is related to the different sources for ice in the Rakaia lobe. Most of the ice was derived from cirques on the main divide 56 km to the north-west at the head of the Rakaia Valley. However the western side of the lobe was derived from the Cameron Glacier whose source was only 29 km away and 13 km from the main divide. This displacement well to the east of the main precipitation divide may have resulted in the Cameron cirques being less favourably situated in relation to the main snow bearing winds. Thus small fluctuations in the regional snowline could have had a greater effect on the mass balance of the Cameron Glacier so that it was unable to maintain its advanced position, and retreated. Thus a prominent end moraine was not able to develop. In contrast, the better nourished main Rakaia lobe was able to retain its advanced position for a longer period and thus build large end moraine forms.

ii) The Late Emily Advances

The late Emily Advance moraines occur 3.6 km north of the earlier moraines. There is no difference in their surface form, and where seen together along the western side of the basin, the lateral moraines of the two sets of advances are concordant.

In the western part of the basin the distinction between the early and late Emily advances is not clear. Numerous small end moraine ridges occur in the ablation moraine south of Johnstone Stream. The outermost late Emily Advance end moraine is probably that at grid ref. Map 7, J35/607400, S81/690567. It is 5 m high, 15 m across and is fronted by an outwash surface that extends southwards for 2.8 km to the Maori Lakes. This surface has a number of small areas of ablation moraine rising 3 m - 5 m above it. In most cases the margins of the ablation moraine areas have been terraced. Thus it is probable that the outwash surface was formed by meltwater reworking the early Emily Advance ablation moraine.

Remnants of two other late Emily end moraine ridges can be seen on both banks of Johnstone Stream. The innermost ridge is fronted by a meltwater channel system cut 6 m below the outwash surface and now occupied by Johnstone Stream.

In the eastern part of the basin the maximum of the late Emily Advance is clearly marked by an end moraine doublet that can be traced north-east for 3.2 km from grid ref. Map 7, J36/645395, S81/735559 to Rikki Spur. The two ridges are 40 m apart, 3 m high and 10 m across. At grid ref. Map 7, J35/655407, S81/746572 a meltwater channel extends south in front of the moraine doublet and opens out onto a small outwash surface that can be traced for 2 km to near Lake Emily. This drainage then flowed via Jacobs Stream into the Ashburton River. For 1 km behind the moraine doublet are remnants of six similar ridges (Map 7).

Late Emily Advance end moraines occur in the northern part of the area between Rikki Spur and the Longman Range. This belt of moraines is 1 km across and is also fronted by remnants of an end moraine doublet. Six further ridges can be recognised behind here. They range up to 10 m high and 25 m across. A meltwater channel extends from within the belt southwards through the early Emily Advance ablation moraine onto the outwash surface described above (p. 175).

A larger number of late Emily Advance end moraine ridges are visible on the eastern side of the basin than to the west. In the east, eight ridges can be seen over a distance of 1 km, while in the west only four have been preserved over 1.2 km. Thus the ice front was presumably again behaving in a similar fashion to that described for the early Emily Advance. Subsequent erosion has removed Emily landforms from the central 2 km of the basin so the precise nature of the relationship between the two contrasting sides of the Rakaia lobe cannot be determined.

iii) Summary of the Emily Advances

During the Emily advances the Rakaia lobe and Cameron glaciers coalesced and extended to the southern end of the Lake Heron basin. At the maximum of the advance, ice reached to within 3 km of the Clearwater lobe. There were clearly numerous fluctuations of the ice front, however only an informal separation into early and late Emily advances can be made. It is not known whether this spatial separation of the two sets of landforms also represents a distinct temporal separation.

During the early Emily advances meltwater and drainage from the western margins of the ice lobe flowed into the Ashburton River near the present Maori Lakes. Discharge from around the eastern part of the glacier escaped into the Stour Valley and flowed to the east of the Clent Hills Range to join the Ashburton River some 12 km to the south. However during the later Emily advances meltwater from both sides of the ice front drained through the Lake Heron basin into the Ashburton River near the present Maori Lakes. At this time most of the meltwater discharge appears to have been from the western part of the ice front.

5. THE LAKE HERON ADVANCES

The Lake Heron Advance landforms are confined to the area around Lake Heron and a narrow area down the centre of the basin. The separation of these from the Emily advances is largely on the basis of the smaller ice extent. Three closely spaced advances reached to within 3.3 km of the later Emily Advance ice positions (Fig. 36). To the east of Mt. Sugarloaf, and south of the Cameron River, Lake Heron Advance lateral moraines clearly cut across the older Emily laterals.

It is not known how much time separated these two Late Pleistocene advances. There was however a period of erosion between the two advances. Most of the post-late Emily landforms were removed prior to the Lake Heron advances.

The Rakaia lobe entered the Lake Stream Valley at 1220 m a.s.l., and 16 km south it was joined at 920 m by the Cameron Glacier. During all three Lake Heron advances the glacier terminated at approximately 710 m a.s.l.

i) Lake Heron 1 Advance

The Lake Heron 1 Advance is marked by a 0.5 km long moraine ridge at grid ref. Map 7, J35/615424, S81/702592. It is 25 m across, has 20° proximal and distal slopes, and rises 10 m above the small remnant of an outwash surface. A more extensive area of this can be traced south-east from near Trig L down the basin for 2.5 km.

The western margin of the Rakaia lobe is marked by a prominent belt of lateral moraines that runs south for 5.4 km south-south-east from the Cameron River. Numerous discontinuous ridges up to 15 m high and 60 m across occur through a height range of 75 m. At grid ref. Map 7, J35/600442, S73/687604, the highest of these lateral ridges has been plastered across part of the Emily ablation moraine.

Lake Heron 1 end moraine has been draped across the northern end of Isolated Hill. This can be seen clearly in Figure 37. It can be traced for 1 km through a total height range of 60 m. The ridge is up to 6 m high and 15 m across. It has an asymmetrical cross-profile, the distal slope being 20° and the proximal slope 9°. This is similar to the push moraine type of Andrews (1975) which would be expected here where the ice was advancing up over such an obstruction.

At grid ref. Map 7, J35/653432, S81/743597 a small area of Lake Heron 1 outwash surface can be seen.

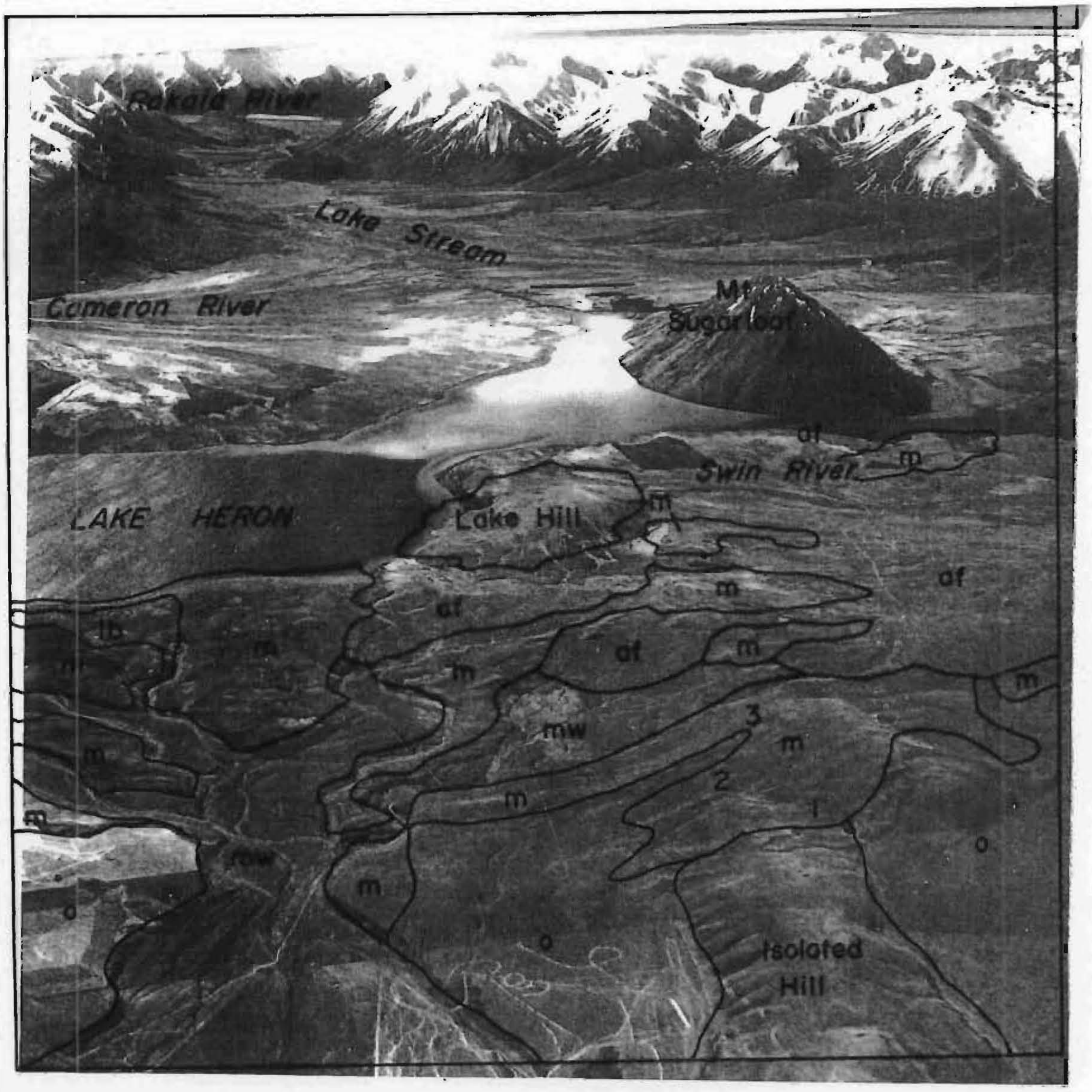


Photo: V.C. Browne, CHCH, 11482.

FIG. 37. Lake Heron and the Lake Stream Valley.
Lake Heron Advance landforms can be seen in the foreground (m = moraines, o = outwash surfaces, mw = meltwater channels, af = alluvial fan, lb = lake bench).

It extends for 1.75 km south down a channel between Isolated Hill and Rikki Spur. This channel is up to 0.75 km wide and is in places over 100 m below the late Emily end moraines. It appears to have carried drainage from the Swin River from around the ice front.

The Swin River has destroyed many of the Lake Heron Advance features along this eastern side of the ice front. There is a gap of some 3 km between lateral moraines preserved on the eastern flank of the basin near Mellish Stream and the Lake Heron landforms on the south bank of the Swin River.

ii) Lake Heron 2 Advance

The Lake Heron 2 Advance reached to within 0.5 km of the Lake Heron 1 terminal position (see Fig. 8). Several remnants of the end moraine ridge are preserved across the western part of the basin floor. From grid ref. Map 7, J35/647437, S73/737602 for 3 km westwards to near the Lake Heron road, three segments from 0.3 km - 1.3 km long can be seen. They are up to 4 m high, 20 m across and are symmetrical, having 18^{o} proximal and distal slopes. The western segment, near the road, has numerous channels extending from it. Meltwater flowing east-south-east from this part of the ice front formed a small outwash surface presumably by reworking Lake Heron 1 ablation moraine.

At grid ref. Map 7, J35/609432, S81/696598 the Lake Heron 2 end moraine is up to 15 m high, 100 m across and has 25^{o} proximal and distal slopes. A 150 m wide meltwater channel follows the ice front for 1 km and issues out onto an outwash surface from the Lake Heron 1 moraine ridge. The channel extends south-east for 2 km and is cut 2 m below the Lake Heron 1 outwash surface.

iii) Lake Heron 3 Advance

The Lake Heron 3 Advance reached to within 0.2 km of the Lake Heron 2 end moraines. A prominent moraine ridge can be seen on the western side of the basin near the Lake Heron 2 end moraine. It is 2 km long, 8 m high and 100 m wide, with 21° proximal and distal slopes. Running around the front of the western half of this ridge is a meltwater channel. This passes through a gap in the Lake Heron 2 end moraine (grid ref. Map 7, J35/612431, S81/697598) and issues onto a narrow outwash surface 3 m below the Lake Heron 2 outwash surface. This younger surface is now traversed by Clent Hills Stream and can be followed south-eastwards for 3.2 km.

At the northern end of Isolated Hill a 1.8 km remnant of the Lake Heron 3 end moraine is preserved (Fig. 37). It ranges from 1.5 m - 4 m high and is approximately 10 m across. Isolated remnants of a second similar ridge can be seen 50 m to the north. On the western side of Isolated Hill the moraine ridge is fronted by an outwash surface that cuts through the earlier Lake Heron moraines and extends south for 1.2 km. The small valley to the east of Isolated Hill is floored by an outwash surface 2.5 m below the Lake Heron 1 outwash remnant. Surface channelling indicates that the Swin River was still flowing around the eastern side of the ice front and discharging by this route. The outwash surface can be traced for 7 km south, to near the Maori Lakes.

Near the south-western end of the lake, the Lake Heron 2 and 3 end moraines are somewhat larger than elsewhere along their length. Presumably more debris was arriving on this part of the glacial surface. This is probably related to a medial moraine that would have formed 6.75 km up-glacier at the junction of the Cameron and Rakaia lobe glaciers.

iv) Summary of the Lake Heron Advances

The Lake Heron advances were the youngest Late Pleistocene advances of the Rakaia lobe glacier. Ice extended 16 km into the Lake Heron basin terminating at approximately 710 m a.s.l. Three separate fluctuations of the ice front can be recognised. They all appear to have been closely spaced as very little erosion occurred between each advance. Most of the ice marginal drainage and meltwater discharge occurred around the western part of the ice front, however an important channel draining the eastern side of the lobe was active between Isolated Hill and Rikki Spur. Both of these outlets coalesced at the southern end of the basin and flowed into the Ashburton River.

The variations in moraine forms on the western and eastern sides of the ice lobe described for the Emily advances does not appear to have occurred during the Lake Heron advances. The whole glacier snout probably behaved uniformly. Thus the fluctuations of the snowline during the Lake Heron advances may have had similar effects on the Rakaia lobe and Cameron glaciers.

6. DEGLACIAL LANDFORMS

An irregular, discontinuous belt of morphologies up to 2 km wide extends across the floor of the basin, south from the Cameron River, around the southern shores of Lake Heron and north between Mt. Sugarloaf and the eastern margin of the basin as far as Smite River. These landforms developed during the early phases of retreat of the Rakaia lobe glacier after the Lake Heron 3 Advance.

As the glacier retreated large areas of ablation moraine were formed. Near the southern shore of Lake Heron numerous, small, discontinuous end moraine ridges can be seen in the ablation moraine (Fig. 37). This indicates that the ice front remained active, with a number of still-stands during the retreat.

The continuing northwards retreat of the ice front, and decline of the ice surface, meant that the marginal drainage and meltwater were having to adjust to constantly changing base levels. Eventually this outflow was no longer able to escape directly southwards through the Lake Heron basin via Gentleman Smith Stream. A pro-glacial lake developed between the retreating Rakaia lobe and the Lake Heron Advance moraines. For a time this continued to drain south, until the Lake Stream Valley became sufficiently ice free for drainage to escape to the north into the Rakaia River.

Figure 38 shows the area on the southern shore of Lake Heron at the head of Gentleman Smith Stream (see also Fig. 37). Here drainage from around the eastern and western sides of the ice front coalesced, passed through a gap in the Lake Heron moraines, and flowed via Gentleman Smith Stream into the Ashburton River. The drainage from the west was composed of meltwater from the Rakaia lobe and Cameron glaciers. That from the east included meltwater and drainage from the Swin River which had switched from its outlet east of Isolated Hill to flow in front of the glacier and inside of the Lake Heron moraines.

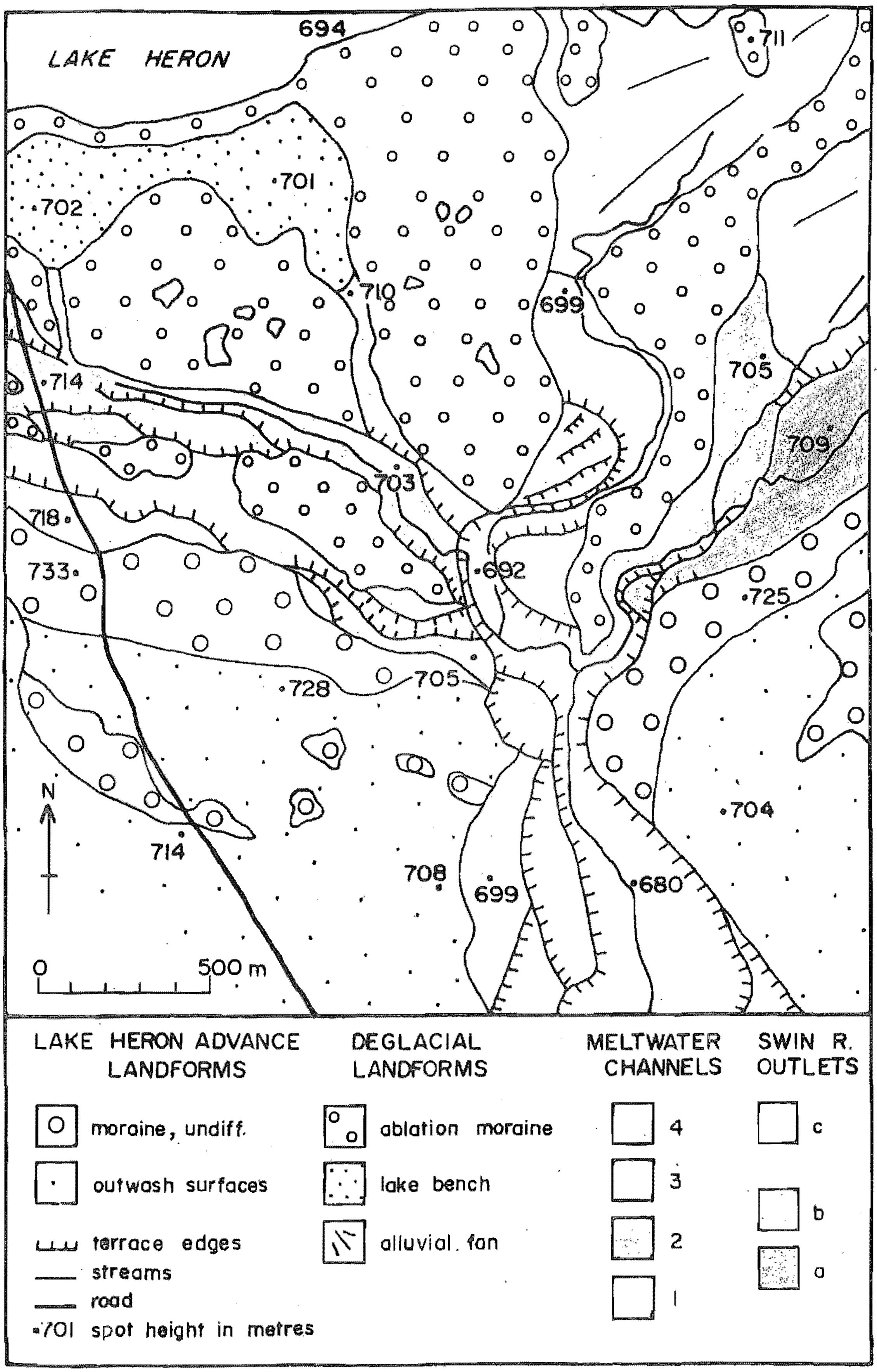


FIG 38 : MAP OF MELTWATER CHANNELS NEAR SOUTHERN SHORE OF LAKE HERON

From the heights and arrangement of the channels and terraces a sequence of channel activity during the various retreat phases has been identified. Each channel contains a number of levels, indicating successive stages of the development of each system. The development of meltwater channels on the western side appears to have overlapped with the development of the Swin River outlets on the east.

Initially meltwater channel No. 1 and Swin River outlet 'a' were active. The ice front at this stage is marked by the moraine ridges 0.5 km behind the Lake Heron 3 end moraine. Subsequently channel No. 2 developed. The glacier had retreated to form end moraine ridges 0.8 km - 1.3 km behind the Lake Heron 3 terminus. During the later phases of activity of channel No. 2, the ice front receded and a pro-glacial lake developed. The lake bench shown on Figure 38 and Map 7 consists of a generally flat area between 5 m - 12 m above the present Lake Heron. Part of the drainage from the western side of the glacier flowed into this pro-glacial lake, whose outlet into channel No. 2 was at grid ref. Map 7, J35/614439, S73/701607. Also at this time Swin River outlet 'b' became active.

By the time meltwater channel No. 3 became active the pro-glacial lake was receiving all the meltwater from the western side of the Rakaia lobe. Two lake outlets were probably active at this time. One can be seen at grid ref. Map 7, J35/622439, S73/710607. Terraces at this level are visible in the large meltwater channel 0.5 km to the east. Thus a second lake outlet was probably active at the head of this channel. However, evidence for this has been buried by part of the Swin River alluvial fan. At this time the Swin River was discharging through outlet 'b'.

During the final phase the pro-glacial lake level had fallen below the lake bench, probably to about the present level of Lake Heron. This lake, and the Swin River, probably both discharged for a time through channel No. 4. However the final phase of usage of this channel was by the Swin River on its own, while the lake had presumably begun to drain north into the Rakaia Valley.

During these early retreat phases the Swin River was building a large alluvial fan out against the retreating ice front. The fan extended from Mellish Stream in the north to outlet 'a' in the south. The complex relationships between this fan, the glacier snout, and the marginal meltwater channels can be seen around the eastern arm of Lake Heron. The fan surface is 40 m above lake level. However several lower ice level controlled meltwater channels are visible between the fan and the lake edge (grid ref. Map 7, J35/648465, S73/740635). Thus the fan surface here had formed before the ice front had retreated from the southern end of Mt. Sugarloaf. It is likely that by the time the glacier had receded from around Mt. Sugarloaf the Swin River was able to discharge via its present course into the proto-Lake Heron. Shortly before this major drainage change, the proto-Lake Heron had stopped flowing south into Gentleman Smith Stream. No other outlet is visible so presumably a subglacial drainage system had developed down Lake Stream Valley. However this was not sufficient to drain the lake which probably grew in size as the ice front continued to retreat (see below).

All the meltwater channels described (Fig. 38) were cut into the moraines and outwash surfaces of the Lake Heron advances. They are degradational features, with each lower surface representing a successive phase of downcutting. However the Swin River, as it reworked the glacial deposits, was able to build up an alluvial fan (see above). The lower parts of this fan encroached on the upper parts of outlets a, b,c, and meltwater channel 4, obscuring some of the landforms here (see Map 7).

The pro-glacial lake described here was clearly related to the retreat of the Rakaia lobe glacier from the Lake Heron basin. It is not related to the "Greater Lake Heron" of Burrows and Russell (1975) which was discussed in Chapter 12. It is not known how large the pro-glacial lake described here became, however the presence of lake beds in the upper Lake Stream Valley (Burrows, *pers. comm.*) would suggest that the lake may have been about twice its present length. The lack of any obvious lake benches at the northern end of the basin makes it difficult to determine its exact size and shape.

CHAPTER 17

THE RANGITATA-ASHBURTON SECTOR OF THE CANTERBURY PLAINS

1. INTRODUCTION

The Rangitata and Ashburton Rivers flow for 50 km to the coast across the southern part of the Canterbury Plains. The deposits along the inner margin of these plains have been discussed above (Chapters 7-12). This section deals with the whole Rangitata and Ashburton sector of the plains, its relationship to the glacial sequences inland, and to the Rakaia-Waimakariri sector of the plains to the north.

The Plains Formations are shown on Map 8, a revision of the mapping of Gair (1968) and Suggate (1973). It is based on field work and mapping across the inner 25 km of the plains between the Rakaia and Rangitata River, and reconnaissance surveys of the lower plains. Extensive use was made of the soil maps of N.Z. Soil Bureau Bulletin 14 (Kear *et al.* 1967).

2. THE CANTERBURY PLAINS

The Canterbury Plains are a striking feature of the landscape of the eastern South Island. They extend for 200 km from the Waipara River south to the Opihi River, and attain a width of over 60 km. Haast (1864c, 1874) recognised that the plains consisted of four distinct alluvial fans associated with the Waimakariri, Rakaia, Ashburton and Rangitata rivers.

These fans were built up by the deposition of greywacke gravels derived from the erosion of the Southern Alps and foothill ranges. This deposition has presumably been going on since the beginning of the Kaikoura Orogeny. Atkins and Hicks (1977) suggest a Quaternary gravel fill of up to 700 m along the Ashburton River. However only the upper part of the Pleistocene is represented by deposits outcropping at the surface. Suggate (1958) correlated three plains formations with glacial advances in the Waimakariri Valley. These correlations were subsequently revised (Suggate 1963b). Most of the detailed work on the geology of the plains has concentrated on the sector between the Rakaia and Waimakariri rivers (Suggate 1958, 1963b, 1973; Soons 1968; Ives 1973a; Wilson 1973). This study has extended this work south as far as the Orari River.

During the Late Pleistocene glaciers extended onto parts of the inner margin of the plains on at least three occasions (Gage 1958, Soons 1963, Suggate 1965, Soons and Gullentops 1973). During the latter of these advances the Woodlands and Windwhistle formations were deposited. The relationships between the moraines, outwash surfaces and plains fan surfaces are best seen alongside both banks of the Rakaia River (Soons 1963, Soons and Gullentops 1973). During subsequent advances ice did not extend beyond the foothill ranges. However an extensive alluvial fan surface, mapped as the Burnham Formation, was deposited. This takes the form of three very large, low angle alluvial fans. The Rakaia and Waimakariri fans coalesced along the line of the present Selwyn River. The Rangitata fan was separated from the Rakaia fan by a smaller area of aggradation formed by the Ashburton River. Thus the three main Late Pleistocene plains surfaces were built up during phases of aggradation related to periods of glacial advance. Each successive fan overtopped the older ones, leaving only small remnants of the older fans along the inner plains margin.

During the Holocene the main rivers have incised deep channels into the fan surfaces. However in places sedimentation has continued. Changing river base levels during the postglacial sea-level rise contributed to the deposition of the Springston Formation. Subsequent progradation of the coastline north of Banks Peninsula has enabled sedimentation to continue in the lower reaches of the Waimakariri River (Suggate 1963b, Ives 1973a). Erosion of the coastline south of the peninsula has caused the Rakaia and Rangitata rivers to continue downcutting.

It is considered appropriate that the surfaces of the plains be considered separately from the inland glacial sequences. While some of the inner plains surfaces can be clearly interpreted as outwash surfaces leading from moraines, sedimentation patterns on the plains have probably been related primarily to their behaviour as alluvial fans rather than outwash surfaces. This sedimentation would have been at a peak during the glacial periods, but it has obviously continued after this time (Suggate 1963b, Ives 1973a).

The plains form a major unit of the South Island landscape. While their formation is clearly related to periods of glacial activity, they cannot be interpreted simply as outwash aggradation features. Thus separate terminologies are used for the plains and inland formations.

3. THE RANGITATA AND ASHBURTON SECTOR OF THE PLAINS

i) Hororata, Woodlands and Windwhistle Formations

These formations are all confined to the inner plains margin. They have been described in Chapters 7-9.

During the Pyramid Advance ice extended onto the inner margin of the plains. Its deposits are here mapped as Hororata Formation. No fluvial surfaces are recognised.

Ice again reached onto the plains during the Dogs Hill Advance. The deposits are here mapped as Woodlands Formation. Some dissected fluvial surfaces can be recognised, but these are insufficient for their relationships to be determined.

During the Trinity Advance ice did not reach as far as the plains. An outwash surface can be traced from a Trinity moraine down the Ashburton Valley. This passes into the surface of the Windwhistle Formation, thus these two formations are believed to be coeval. The alluvial fan form of the surface of the Windwhistle Formation has been described above (Chapter 9). The Windwhistle Formation surfaces are common along the inner plains between the Ashburton and Rakaia rivers. The deposits are all slightly weathered and are overlain by at least 1 m of loess. In the Rakaia Valley the deposits of the Tui Creek Advance in the Rakaia Valley (Soons 1963, Soons and Gullentops 1973) are mapped as the Windwhistle Formation (Suggate 1965).

The correlation of the Hororata and Woodlands formations as mapped in the study area, with these formations along the Rakaia and Waimakariri sectors of the plains, is based in each case on the general similarity of deposits and stratigraphic setting in relation to the more confidently correlated remnants of the Windwhistle Formation. The Woodlands and Windwhistle formations are overlain by different soil groups (Kear *et al.* 1967), and the former commonly has two loess sheets on its surface (see Chapter 8).

ii) The Burnham Formation

The Burnham Formation is the most extensive of the plains formations, extending from the inner plains margin to the coast. The portion near the inner plains margin has been described above (Chapter 10).

Near the Rangitata River the surface form of the Burnham Formation is that of a very large, low-angle, multi-storey alluvial fan. It extends from the Hinds River south-west for 22 km to Coopers Creek. The highest surface is on the north bank of the Rangitata River. At the gorge mouth it is 70 m above the river (427 m a.s.l.) and it declines to approximately 20 m above river level at the coast. At 13.5 km downstream from the gorge this main surface overtops the older Windwhistle Formation and extends eastwards for 16 km to the Hinds River, sloping away from the Rangitata River at 3.5 m/km. From here to the coast there is a single Burnham Formation surface. On the south bank of the river several terrace levels are preserved, most lower than that on the north bank. From the gorge south for 6.5 km the main surface is 60 m above the river. At Peel Forest, 14 km from the gorge, the surface of the Burnham Formation slopes extends 2.5 km westwards from the Rangitata to Coopers Creek. This width increases to 6 km at the coast. In this stretch four different levels can be distinguished. The highest of these is at Peel Forest. It consists of a small terrace remnant (Map 4, K37/703987, S91/790112) that is at the same height as the main Burnham surface on the north bank. The next lower surface, 10 m below, can be traced for 7 km south to Arundel where it is separated from the third surface by a 3 m terrace riser that runs south for 3 km from grid ref. K37/725921, S91/812039 towards Coopers Creek. This third surface is 21 m above river level. The boundary between the third and fourth surfaces is marked by a 5 m terrace edge that can be followed south for 7 km from grid ref. K37/734889, S91/822004. This lowest surface extends for 27 km, declining from 15 m above river level (182 m a.s.l.) to 5 m a.s.l. at the coast. It is possible that some of these lower surfaces belong to the younger St. Bernard Formation. There is no satisfactory means of determining this as these surfaces are too far from occurrences of the St. Bernard Formation near the gorge mouth (see Chapter 11 and below).

The Burnham Formation surfaces are separated from the Hakatere formation outwash surfaces at the southern end of Pudding Valley by only 3.5 km through the Rangitata gorge. Projections of these surfaces clearly meet in the gorge (see Fig. 9). Thus the Burnham and Hakatere formations are believed to be coeval. However the whole Burnham Formation is not interpreted as a continuation of the Hakatere outwash surfaces. Its deposition was clearly related to the Hakatere Advance, however little is known about the age relationships of the various Burnham surfaces. Each surface is probably a composite feature, and the lower ones may be in part degradational and could have formed some time after the Hakatere Advance. Thus in the absence of more confident means of correlation, the Hakatere and Burnham formations are usefully considered as separate, although related features.

The Burnham Formation can be traced down the Ashburton sector of the plains from near the Stour River for 49 km until it disappears beneath the younger Springston Formation. The surface form is not that of a classical alluvial fan, like those associated with the Burnham Formation along the Rangitata River. A single surface is recognised sloping gently to the north at 1 m/km from the Hinds to the Ashburton River, with the Ashburton River flowing close to the southern margin of the Rakaia River Burnham Formation alluvial fan.

The Rangitata and Ashburton Burnham formations can be correlated by height across the Hinds River, and both are overlain by the same soil type (Kear *et al.* 1967). Thus the Ashburton sector of the Burnham Formation was also presumably forming at the time of the Hakatere/Emily advances. At this time the Ashburton, Clearwater and Rakaia lobe glaciers were all discharging into the Ashburton River. Although no outwash surfaces can be traced through the 11.5 km gorge, the Ashburton River must have been carrying an appreciable sediment load. However as it passed out onto the plains it became confined between the vigorously aggrading Rangitata and Rakaia alluvial fans. Free channel movement of the Ashburton River was thus inhibited, resulting in a constricted aggradation area controlled by the rate and level of aggradation of the flanks of the Rangitata and Rakaia fans. The present slope of this surface to the north is probably the result of some degradation by the river prior to its establishing its present course.

The Burnham Formation can be correlated across the whole Canterbury Plain by its stratigraphic setting in relation to older formations and the similarity of weathering of the deposits. The formation is overlain by only one loess layer generally less than 1 m thick (Bruce *et al.* 1973), and the dominant soil types are the Lismore stony silt loams (N.Z.S.B. Bull. 14).

iii) The St. Bernard Formation

The St. Bernard Formation has not been mapped on the Canterbury Plains by any previous workers. However, small remnants of this formation have been recognised along the inner plains margin near the Rangitata River (see Chapter 11). These surfaces can be confidently traced up valley through the Rangitata gorge into the Spider Lakes Advance outwash surfaces. Down valley some of the lower Burnham Formation surfaces should possibly be included in the St. Bernard Formation (see above). It is highly likely that similar surfaces exist within the gorges and along the inner plains margins of the Rakaia and Waimakariri rivers (e.g. Soons 1963). However the difficulties of terrace correlation through these gorges have so far prevented their being identified.

iv) The Springston Formation

The Springston Formation was originally proposed by Suggate (1963b) for a small alluvial fan surface along the lower reaches of the Waimakariri River. It was considered to be early Holocene in age. Suggate (1973) maps large areas of this formation along the Ashburton River. This is continued and extended here on Map 8.

Along the Rangitata River the Springston Formation consists of terraces 3-8 m above the present river level. It is much more widespread along the Ashburton River and it is also mapped along the Hinds River. It can be distinguished from the Burnham Formation by the different soil types (Kear *et al.* 1967). The wider occurrence of this formation in the Ashburton River plains sector can be attributed to the river not being incised below the level of the plains. It has thus been able to extend laterally over a wide area. The Rangitata River is incised well below the main plains level, so that the Springston Formation is here of more limited extent.

In places this formation includes some very low terraces close to the rivers. These are probably recently abandoned parts of the river flood plains and should be mapped as "Recent" river gravels. However they are of limited extent, and for convenience are included in the Springston Formation.

When the Springston Formation was first proposed by Suggate (1963b) some difficulty was experienced in determining its age. On the basis of its stratigraphic setting, and a radiocarbon date from the overlying soil, it was considered to be early Holocene in age. No further information has emerged, and this interpretation is followed here.

Although the formation covers a wide area it is probably only a few metres deep, and thus of quite limited actual volume. It is very poorly exposed, however soil profile analyses in N.Z.S.B. Bull. 14 suggest a predominance of sand and silt parent materials, especially away from the rivers. Ives (1973b) maps large areas of rewashed loess associated with the Hinds and Ashburton rivers in the area mapped as Springston Formation. The upper parts of this formation are interpreted here as having been deposited during periods of flooding by the Hinds and Ashburton rivers. It seems probable that this deposition has obscured the formerly more extensive St. Bernard Formation.

The Springston Formation cannot be correlated with any glacial advance inland. Its deposition is probably related in part to changing river base levels caused by the post-glacial rise in sea-level, and to the erosion of glacial deposits inland during the period of deglaciation.

PART FOUR: SYNTHESIS AND CORRELATION

CHAPTER 18

THE GLACIAL CHRONOLOGY IN THE RANGITATA AND ASHBURTON VALLEYS

1. CRITERIA FOR ESTABLISHING GLACIAL CHRONOLOGIES

i) Introduction

In the first detailed account of a New Zealand glacial sequence, Gage (1958, p. 126) stated that the aim of his work was "...to present the hypothesis that, during the Late Pleistocene, the area experienced a number of major glacial advances separated by partial or total withdrawals of ice..." He erected a glacial chronology based on the field relationships of the morphologies and deposits (*ibid.*, p. 128), including "differences of elevation, distribution, depth, and intensity of weathering, and defacement of original surface detail..." (*ibid.*, p. 127). Since this pioneering work glacial chronologies have been established in other South Island valleys using essentially the same criteria. Under the assumption of probable general synchroneity of glacial events, workers have attempted to correlate their chronologies with other known glacial chronologies. This is also one of the aims of this thesis. A glacial chronology for the Rangitata and Ashburton valleys will be proposed below, and will be correlated with other South Island glacial chronologies.

The terms glacial sequence and glacial chronology as used here, are not synonymous. A glacial sequence identifies a number of discrete glacial advances. A glacial chronology groups these advances into various periods, and as such involves a subjective interpretation of the evidence used to define the glacial sequence. It is thus a chrono-stratigraphic classification based on essentially climatic criteria (Bowen 1978, Burrows 1978).

ii) Criteria for Establishing a Glacial Chronology

The criteria used to differentiate the various glacial advances have been discussed above (Chapter 6). They are similar to those originally used by Gage (1958) and most subsequent workers. Establishing glacial chronologies has rested upon subjective interpretations of the magnitude of time differences implied by variations in the post-depositional modification of landforms and deposits. Gage (1958) suggested the need for more quantitative testing of chronologies, particularly in relation to weathering parameters. Recently this suggestion has been taken up and attempts have been made to define glacial chronologies using relative dating techniques. These techniques involve the measurement of age dependent changes that affect deposits, landforms and cover deposits.

Cover deposits, including soils and loess, on glacial and fluvioglacial surfaces of different ages have been studied by Leamy (1973), Webb (1976), and McGregor (1978). They were able to differentiate morphologies on the basis of a variety of soil profile parameters. The applicability of paleopedology and loess studies to the New Zealand Quaternary succession is discussed by Leamy *et al.* (1973a) and Ives (1973b). These studies were all carried out in relatively small areas. Larger scale soil studies would encounter difficulty in separating the differences due to age, environmental and parent material factors.

Work has been carried out on many aspects of glacial and fluvioglacial deposits. Marden (1975) had difficulty distinguishing outwash deposits on the basis of their grain size and shape parameters. However McGregor (1978) was able to differentiate till sheets using these parameters, and also till fabrics. Weathering characteristics of deposits have also been measured. Marden (1975) was able to distinguish the relative ages of deposits from changes in their clay mineralogy. Determinations of clast and matrix colour have also proved useful (Mansergh 1977, McGregor 1978). Measurements of the specific gravity and percentage absorption of gravels by Mansergh (1977) and McGregor (1978) have shown gross age related differences. Soons (*pers. comm.*) applied the specific gravity technique over a wider area but obtained less certain results.

Weathering rinds on exposed greywacke boulders have been used as an absolute and relative dating tool in a number of areas (Chinn 1975, 1980; Mabin, *in prep.*). However this method can only be applied to Holocene deposits.

The results of these studies suggest that in areas where environmental factors can be assumed to be uniform, age dependent changes in the nature of deposits and cover beds can be used to differentiate morphologies of different ages.

These parameters provide a quantitative means of assessing glacial chronologies. It is encouraging to note that the most detailed work of this kind carried out by McGregor (1978 confirmed the subjective, qualitative chronology of glacial advances in the Lake Tekapo area proposed by Tuck (1975).

In the Rangitata and Ashburton area semi-quantitative relative age determinations have not been made, mainly because the size and nature of the field area rendered them beyond the scope of this investigation. Analysis of the deposits was not possible as no representative suite of deposits relating to any one of the ice bodies could be obtained. Thus in this study qualitative assessments of morphological and lithological differences have had to be relied upon. These have been the basis of the chronology and the correlations presented below.

2. THE GLACIAL CHRONOLOGY OF THE RANGITATA AND ASHBURTON VALLEYS

i) Introduction

The glacial sequences in the Rangitata and Ashburton valleys have been described above. From the evidence used (see Table 5) a chronology of glacial advances can be proposed based on subjective interpretation of the magnitude of time differences implied by variations in the post-depositional modification of landforms and deposits.

It should be stressed that the glacial sequence here is possibly incomplete. Evidence for smaller glacial events may have been removed by some of the advances recognised here. In terms of describing the configuration of the present landscape, these unrecorded glacial advances are unimportant.

However, in terms of a glacial chronology this means that the number of glaciations proposed is probably the minimum number that has occurred.

Much depends upon the definitions used of glacials/ interglacials and stadials/interstadials. These are discussed by Bowen (1978, pp. 100-108). There is no evidence in the field area that has any direct bearing on this problem. The definitions followed here are those of the American Code (1961). A glaciation is defined as "a climatic episode during which extensive glaciers developed... An interglaciation was an episode during which climate was incompatible with the wide extent of glaciers..." (*ibid.*, p. 660).

The identification of glacial periods presumes the existence of intervening interglacial periods. However in most glaciated areas in New Zealand there is no direct evidence for these interglacials. Thus the chronology proposed, of alternating cold/warm phases, is based only on evidence for the cold periods.

ii) <u>The Glacial Chronology</u>

At least three glacial periods are believed to be represented by the glacial sequences in the Rangitata and Ashburton valleys. However the evidence could represent as many as six glacial periods.

Weathering of the deposits clearly separates the Pyramid and Dogs Hill advances from the Trinity, Hakatere/ Emily and Spider Lakes/Lake Heron advances. Differences in ice extent, elevation and dissection of morphologies, and subtle contrasts in the weathering of deposits are used further to subdivide the sequence.

The oldest recognised glaciation is represented by the Pyramid Advance. Morphologies are too dissected to be identified and the deposits are well weathered, with individual clasts being easily broken by a hammer blow. The precise relationship between this formation and the details of the present landscape is difficult to determine.

The distribution and nature of the morphologies of the next younger Dogs Hill Advance suggest that an interglacial separates it from the Pyramid Advance. Morphologies, while subdued, can be identified and their relationships to the present landscape more clearly determined. The deposits are weathered, but individual clasts are difficult to break with a hammer. There is clear evidence for two stadials within the Dogs Hill Advance. They appear to have been spatially well separated, so it is possible that two full glacial periods are represented.

The Trinity, Hakatere/Emily and Spider Lakes/Lake Heron advances are all believed to have occurred during the last glaciation. The indicated ice extents are much smaller than the Dogs Hill Advance, and the morphologies and deposits are clearly more freshly preserved. Trinity deposits can be seen at river level in the main valleys, thus there had been sufficient time prior to this advance for removal of older deposits. These differences indicate that an interglacial separated the Dogs Hill and Trinity advances.

The Trinity Advance is believed to be separated from the younger advances by at least a long interstadial interval. The morphologies are more subdued and the matrix of the deposits shows some weathering. It is possible that the Trinity Advance represents a separate glaciation.

The main difference between the Hakatere/Emily and Spider Lakes/Lake Heron advances is in ice extent. Morphologies are only slightly subdued and deposits are unweathered. A minor interstadial is thus believed to separate these advances. They are the youngest to have reached beyond the alpine region into the intermontane basins. Since Spider Lakes/Lake Heron time there has been a general period of deglaciation covering the Holocene period. There was a significant readvance in the Early Holocene, and there is evidence for more recent small glacial advances (Burrows 1975, Burrows and Gellatly, *in prep.*). However, the overall pattern of retreat is continuing and the remaining glaciers are very small.

The Late Pleistocene glacial chronology of the Rangitata and Ashburton valleys is outlined below from youngest to oldest:

TABLE 5. The glacial chronology in the Rangitata and Ashburton valleys.

Postglacial
SPIDER LAKES/LAKE HERON ADVANCES (3 Stades)
Minor interstadial
HAKATERE/EMILY ADVANCES (Several Stades)
Major interstadial
TRINITY ADVANCES (Several Stades)
Interglacial
DOGS HILL ADVANCE (2 Stades)
Interglacial
PYRAMID ADVANCE (2 Stades?)

CHAPTER 19

CORRELATION

1. INTRODUCTION

Since the pioneering work of Gage (1958) and Gage and Suggate (1958) attempts have been made to correlate glacial sequences and to establish a Glacial Chronology of the New Zealand Pleistocene (*ibid.*; Gage 1961; Suggate 1965). In this section glacial chronology of the Rangitata and Ashburton valleys will be correlated with other glacial chronologies, and in the light of this the current status of the New Zealand Glacial Chronology of Suggate (1965) will be assessed.

2. METHODS OF CORRELATING GLACIAL CHRONOLOGIES

The correlation of glacial chronologies has always been problematic. Ideally the various sequences should be correlated on the basis of their absolute ages. The only absolute dating method applicable to South Island sequences on a wide basis is the radiocarbon technique. However the range of this only renders it useful in dating the latter part of the most recent glacial period. Further difficulties arise from the lack of suitable dateable material, particularly east of the Main Divide, and the frequent difficulty in determining the precise stratigraphic and morphological interpretation of the dated horizon with respect to a glacial event. Thus for the bulk of the Late Pleistocene, no method of absolute dating of glacial events is currently available.

Most workers, following the practice of Gage and Suggate (1958), have erected local chronologies and attempted to correlate these with other glacial chronologies. The methods of correlation, which have been summarised by Suggate (1965, p. 9), consist of assessments of similarities of post-depositional modification and the morphological/stratigraphic setting of the evidence. These methods do have some value in areas where environmental factors are broadly similar. The most important of these factors appear to be geomorphic setting, rock type and climate. The latter two have important influences on post-depositional landform modification, soil development and weathering of deposits. The combination of geomorphic setting and glacial climate influences the style of glacier behaviour and hence the landforms and deposits produced. On this basis glacial chronologies in the Canterbury region, extending from the Mackenzie Basin north to the Waiau Valley, may be reasonably correlated. This area has a uniform rock type and similar climatic pattern. However glacial sequences in this region and in South Nelson, North Westland, Central Otago and Southland all occupy contrasting geomorphic, geologic and climatic settings. Correlations from region to region can often be in error. For example, Suggate (1965) correlated the Hawea Advance in Central Otago (McKellar 1963) with the Reid Stream Advance in South Nelson on the basis that both were the youngest Late Pleistocene advances recorded in each valley. However, radiocarbon dates place the

Hawea Advance some time prior to 15,100 yrs B.P. (McKellar 1963) and the Reid Stream Advance later than 14,800 yrs B.P. (Mabin 1976). Similarly, stadial conditions are believed to have prevailed in North Westland between 22,300 yrs - 18,000 yrs B.P. (Suggate and Moar 1971, Nathan and Moar 1973) while an interstadial occurred between 22,800 yrs - 19,750 yrs B.P. in Canterbury (Soons and Burrows 1978). These examples suggest that during the last glaciation there may not have been synchroneity of advances from region to region. In the absence of absolute dating control or detailed relative dating data, the interregional correlation of glacial chronologies is not considered to be worthwhile. Thus the correlation of the Rangitata/Ashburton glacial chronology will not be extended outside the Canterbury Region. The correlations discussed are with the Mackenzie Basin, Rakaia, Waimakariri, Hurunui and Waiau valley glacial chronologies (see Table 6).

3. CORRELATION

i) Mackenzie Basin

The southernmost glacial sequences in the Canterbury Region are preserved in the Mackenzie Basin. Three major sequences are recognised: the Lake Ohau sequence (Mansergh, *in prep.*); the Lake Pukaki sequence (Speight 1963; Mansergh 1973, 1977; Bunting 1978); the Lake Tekapo sequence (Tuck 1975, McGregor 1978). Common terminology for the advances has been used in these three areas. The two youngest Tekapo and Mt. John advances were closely spaced multiple events. They can be correlated with the Spider Lakes/Lake

Heron and Hakatere/Emily advances respectively. The Balmoral Advance is considered to be significantly older than the Mt. John. Morphologies are subdued and the deposits are slightly weathered (Mansergh 1977). Correlation with the Trinity Advance is proposed. The Wolds Advance is separated from the Balmoral by an interglacial (Mansergh 1973, 1977; Tuck 1975). Deposits are distinctly weathered and morphologi very subdued. Thus the Wolds and Dogs Hill advances can be correlated.

ii) Rakaia Valley

The Late Pleistocene glacial sequence in the Rakaia Valley has been studied by Soons (1963), Carryer (1967), Rains (1967), Soons and Gullentops (1973), and Soons and Burrows (1978). It has been shown that a large lobe of the Rakaia glacier entered the Lake Heron basin. Correlations can thus be made via moraines through the Lake Stream Valley and by fluvial surfaces along the inner margin of the plains.

Carryer's (1967) mapping of the northern flank of the Mt. Hutt Range was continued along the southern bank of the Rakaia River using aerial photographs. Lateral moraines of the Acheron and Bayfield advances can be traced to the mouth of Lake Stream. These can then be linked up the Lake Stream Valley to the Lake Heron and Emily moraines respectively. The Tui Creek and Trinity advances can be correlated along the inner plains margin via the surfaces of the Windwhistle Formation as described above (Chapter 17). Similarities of morphologies and deposits suggest the likely correlation of the Woodlands and Dogs Hill advances.

iii) Waimakariri Valley

The glacial sequence in the Waimakariri Valley is described by Gage (1958), and Gage and Moar (1973). While direct correlation is not possible, this sequence displays obvious similarity with the Rangitata/Ashburton sequences. The lack of weathering of the deposits and morphologies of the two youngest closely spaced Poulter and Blackwater advances invites correlation with the Spider Lakes/Lake Heron and Hakatere/Emily advances. The Otarama Advance landforms are subdued, and Gage (1958) postulates a long interstadial between this and the Blackwater advances. This is similar to the relationships of the Trinity Advance. Similarities of weathering and stratigraphic setting also suggest the correlation of the Woodstock and Dogs Hill advances. The Avoca and Pyramid advances exhibit similarities in weathering of deposits and topographic expression and are thus correlate

iv) Hurunui Valley

The glacial sequence in the Hurunui Valley has been studied by Powers (1962) and Suggate (1965). Only two sets of young moraines are recognised although numerous, higher terrace levels attest the extensive Late Pleistocene glaciation of the valley (Powers 1962). Little information has been presented on the weathering of deposits or dissection of the various surfaces, thus correlation is largely based on counting back from the youngest advances and must consequently be very tentative. Thus the Lake Sumner and Sisters Creek moraines (Suggate 1965) are presumably correlatives of the Spider Lakes/Lake Heron and Hakatere/Emily advances respectively. The Three Trees moraine (Powers 1962) may correlate with the Trinity Advance. The 'High Terraces' of Powers (1962) were probably formed during a correlative of the Dogs Hill Advance. The 'High Warped Surface' is underlain by well weathered gravels and may be correlated with the Pyramid Advance.

v) Waiau Valleys

The northernmost glacial sequences studied in the Canterbury Region are in the Waiau valleys. A glacial sequence has been recognised (Clayton 1968) that shows similarity with the Rangitata/Ashburton sequence. Four advances are recognised in the last, or 'Hope', glaciation of Clayton. Deposits show no recognisable weathering, and morphologies are freshly preserved (*ibid.*, p. 761). Thus the youngest Lewis Advance is correlated with the Spider Lakes/Lake Heron advances. Correlation of the older, last glaciation advances is more difficult. Clayton identifies three, while only two such advances have been recognised in the Rangitata/Ashburton area. Clayton (*ibid.*, p. 763) differentiates Glenhope from younger Glynnwye surfaces on the basis of soil differences and the better preservation of surface channelling on the younger surfaces. This is similar to the differences between the Hakatere and Trinity advances. Thus the Glennwye advances are correlated with the Hakatere/ Emily advances, and the Glenhope and Leslie Hills advances with the Trinity advances. This causes a slight alteration of the correlation between the Waiau and Waimakariri valleys shown by Clayton (1968, Table 1, p. 756). However, the alternative suggested here was indicated as a possibility (*ibid.*, p. 765). Horseshoe glacial deposits are weathered and morphologies while subdued are recognisable. This advance is correlated with the Dogs Hill Advance. Kakapo glacial deposits are well weathered and morphologies largely unrecognisable. Correlation with the Pyramid Advance appears appropriate.

vi) Summary of Correlations

The correlations of the various Canterbury Region glacial chronologies are shown in Table 6. It should be noted that although numerous stadials have been recognised by most workers within the last glaciation, the correlation of these is not attempted. Such detailed correlations should not be attempted in the absence of more numerous radiocarbon dates. A tentative chronology of the more recent Late Pleistocene advances is also presented. This is based on the few radiocarbon dates obtained in the Canterbury area.

This chronology must be regarded as tentative, particularly without absolute or relative dating control. However as it stands it is believed adequately to reflect the nature of the glacial chronologies discussed herein.

The correlation of the presumed equivalents of the Trinity and Dogs Hill advances does merit some discussion. The possibility that the Trinity Advance represents a separate glaciation has been discussed above. The Balmoral Advance has been placed in its own glaciation on the basis of specific gravity data by Mansergh (1977). Soons and Gullentops (1973) suggested that: "Serious attention must

TABLE 6. Correlation of glacial chronologies in the Canterbury region.

^{14}C Yrs B.P..	Mackenzie Basin	Rangitata/ Ashburton Valleys	Rakaia Valley	Waimakariri Valley	Hurunui Valley	Waiau Valleys
<11 950 [1]	Tekapo Advances	Spider Lakes/ Lake Heron Advances	Acheron Advances	Poulter Advances	Sumner moraine	Lewis Advance
		M I N O R	*I N T E R S T A D I A L*			
<19 750 [2]	Mt. John Advances	Hakatere/ Emily Advances	Bayfield Advances	Blackwater Advances	Sisters moraine	Glynnwye Advances
		M A J O R	*I N T E R S T A D I A L*			
>45 000 [3]	Balmoral Advance	Trinity Advance	Tui Creek Advances	Otarama Advances	Three Trees moraine?	Glenhope/ Leslie Hills
			I N T E R G L A C I A L			
	Wolds Advance	Dogs Hill Advance	Woodlands Advance	Woodstock Advance	High surfaces?	Horseshoe Advance
			I N T E R G L A C I A L			
	pre-"BOG"?	Pyramid Advance		Avoca Advance	High warped surfaces?	Kakapo Glaciation

[1] Bunting (1978)

[2] Soons and Burrows (1978)

[3] Gage (1958)

be given to the possibility that the Tui Creek Advance represents a distinct glaciation within the now much extended concept of the Last Glaciation (Flint, 1971..." This latter interpretation is favoured here. Recent work by Soons (*pers. comm.*) casts doubt on the correlation of the Woodland and Woodstock advances. On the basis of specific gravity data the Woodlands Advance appears to be younger than the Woodstock Advance. A resolution of this problem may be proposed from the two stadials recognised within the Dogs Hill Advance. The earlier may correlate with the Woodstock Advance, and the younger with the Woodlands. Both stades of this glaciation may not have been identified or may not be preserved in the Rakaia and Waimakarari valleys. This again raises the possibility that the Dogs Hill Advance may represent two glaciations. Further testing of the specific gravity technique in the Rangitata/Ashburton area may help to resolve this problem.

4. THE GLACIAL CHRONOLOGY OF THE NEW ZEALAND LATE PLEISTOCENE

A glacial chronology of the New Zealand Late Pleistocene was proposed by Gage and Suggate (1958) and amended by Gage (1961) and Suggate (1965). This latter chronology was based on work in the northern part of the South Island. It involved the interregional correlation of numerous glacial sequences. These have been questioned by Soons (1966), Gage (1971, 1980), Gage and Moar (1973), Soons and Gage (1973), Mabin (1976) and Bell (1977) in relation to the number of glaciations, the criteria used to recognise them and the interregional correlations of glacial sequences. However, due to the appearance of the chronology in an official N.Z. Geological Survey Bulletin (Suggate 1965) it has become widely accepted both in New Zealand and overseas (for example, see Fleming 1975, Flint 1971). Since 1965 a further twelve glacial sequences have been studied (Fig. 2). Thus a reassessment of Suggate's chronology and correlations appears timely, particularly as established views of the Pleistocene glaciations have also been radically altered (Bowen 1978).

Suggate's Glacial Chronology was based on the Taramakau glacial sequence on the West Coast where the relationship between glacial advances and interglacial high sea levels could be determined. Recent work in this area by Soons and Bell (1980) appears to require that the chronology be extensively revised. In the light of these considerations the correlation of the glacial chronology in the Rangitata and Ashburton valleys with the N.Z. Glacial Chronology of Suggate (1965) appears to be inappropriate at this time.

Due to the potential inconsistencies in the terrestrial record of glacials and interglacials, Bowen (1978) recommends that Pleistocene chronology be based on deep sea cores. To this end an oxygen isotope record for the New Zealand region is being attempted (Kamp, *in prep.*). However, there is still potential for the relationships between terrestrial glacial and interglacial chronologies to be determined in New Zealand. An absolute chronology of the high sea levels recorded in the Wanganui Region (West Coast North Island) is being determined (Pillans and Kohn 1980). Work in the Wairau Valley (Northern

South Island) on loess and tephra deposits may provide absolute dating control on some of the older glacial outwash surfaces (Eden, *in prep.*). The reassessment of the Taramakau glacial/interglacial chronology (Soons and Bell, *in prep.*) is thus very important. This chronology must be soundly based on absolute and relative dates.

As most large scale glacial sequences in the South Island have now been described, work should progress towards establishing regional glacial chronologies. Relative dating techniques would appear to be most useful, although these may have to be differently applied from region to region. In the Canterbury area determinations of specific gravity, clay mineralogy and soil properties appear to offer some potential as relative dating parameters. Correlation of interregional glacial chronologies with the Taramakau chronology should be based on quantitative relative dating data.

A detailed chronology of the latter part of the last glaciation may be possible using ^{14}C dates. Detailed differentiation of older glaciations will be more difficult due to the lack of preservation of deposits. However, potential does exist in the Rangitata and Ashburton valleys.

The Dogs Hill and Pyramid formations are here quite extensively preserved and more detailed work may allow for a closer subdivision of these advances.

A chronology of the New Zealand Late Pleistocene would appear to be possible in the near future. This will, however, involve much interdisciplinary study with important contributions from geographers, geologists, pedologists, palynologists and oceanographers.

CHAPTER 20

SUMMARY AND CONCLUSIONS

The main aim of this thesis has been to describe the landscape in the Rangitata and Ashburton valleys. The major elements of this landscape: the mountains, intermontane basins and plains, are structurally controlled and can be related to the differential uplift of the Kaikoura Orogeny. The detailed character of the landscape is due to repeated glaciations during the Late Pleistocene. From the nature of the morphologies and deposits a sequence of glacial advances can be recognised.

Lithostratigraphic mapping at a scale of 1:50,000 allowed for complete coverage of the field area and identification of the major areas of glacial and fluvial deposits formed during the various advances. Geomorphic mapping at a scale of 1:25,000 of selected areas has provided detailed information on the morphologies associated with the younger advances.

Several aspects of the glacial sequences studied here are of particular interest. The absence of major rivers in the Lake Clearwater and Lake Heron basins has resulted in the preservation of extensive areas of glacial and fluvioglacial landforms. This has allowed for the analysis of ice front behaviour and sedimentation patterns in a number of areas. An unusually large area of deglacial landforms is preserved in the Lake Clearwater basin. A deglacial sequence has been identified that permits a detailed analysis of the style of retreat of a major ice lobe. In the Lake Heron basin a smaller area of deglacial landforms is preserved. Here a complex history of meltwater drainage, alluvial fan deposition and pro-glacial lake level fluctuations has been determined. Mapping has also enabled the surfaces of the Canterbury Plains to be more firmly correlated with the glacial sequences.

From the criteria used to differentiate the various advances, a Late Pleistocene glacial chronology of the Rangitata and Ashburton valleys has been proposed:

SPIDER LAKES/LAKE HERON ADVANCE
minor interstadial
HAKATERE/EMILY ADVANCE
major interstadial
TRINITY ADVANCE
interglacial
DOGS HILL ADVANCE
interglacial
PYRAMID ADVANCE

This glacial chronology may well be the minimum number of glaciations represented by the morphologies and deposits described. Such a chronology is appropriate when considered in its own setting, as it reflects the major landforming events in the history of the study area. However it is probably not appropriate when considered in relation to the actual chronology of the Late Pleistocene, particularly as evidence for smaller glacial periods may have been destroyed by the larger advances recorded here.

Correlation of this sequence with others in the Canterbury region appears to be possible. The chronology of glaciations proposed here agrees well with those of other workers. Correlation with glacial sequences in other regions is not possible due to insufficient data, particularly on relative dating parameters. Correlation with the New Zealand Glacial Chronology is not possible for similar reasons, and because it is presently under extensive review.

The establishment of a New Zealand Glacial Chronology of the Late Pleistocene faces two important problems: the number of glaciations that have occurred, and interregional correlation of glacial sequences. While the latter must be based on absolute and relative dating techniques, the former may in part be assessed in the Rangitata and Ashburton valleys. Older glacial deposits are more extensively preserved here than elsewhere. Detailed analysis of the morphologies and deposits of the Pyramid and Dogs Hill advances could provide more data on earlier glaciations.

Clearly the chronology of the Late Pleistocene in New Zealand can no longer be based solely on a terrestrial glacial/interglacial sequence. Although the identification of glacial sequences provides impressive evidence for periods of glacial expansion, it is an incomplete data source, both for the glacial and interglacial periods. A multi-disciplinary approach to the establishment of a chronology is required. There is great potential for this in New Zealand where numerous types of Pleistocene landforming and sedimentary processes have been operating.

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APPENDIX 1

POLLEN ANALYSES OF ORGANIC SEDIMENTS

Organic deposits were located in two exposures. These have been described in Chapters 8 (pp. 58-60 and Fig. 14) and 11 (pp. 99-101). These were analysed by Dr N.T. Moar (*pers. comm.* 28/8/80) who provided the descriptions and notes given below.

Pollen analysis from sites in the Rangitata/Ashburton area. Figures and percentages of a pollen sum which excludes pollen of aquatics (*Isoetes*) and fern spores.

Pollen Type	Haast Gully No. 1	Rangitata Gorge No. 2 (Upper)	Rangitata Gorge No. 3 (Lower)
Bulbinella			2
Caryophullaceae	3	2	
Stellaria	tr		
Compositae	10	4	6
Taraxacum types	tr		
Coprosma	5	10	15
Cruciferae	1		
Cyperaceae	31		
Dacrydium bidwillii			2
**Dacrydiumites*		22	
Epacridaceae	5		2
Gentiana	tr		
cf. *Gleichenia*		4	
Gramineae	13	4	3
Gunnera	2		
Haloragis	3		
Hoheria			2
H. lyallii type			5
Isoetes spores		2	124
Malvaceae			5
**Microcachryidites*		14	
Monolete spores	tr	10	
Muehlenbeckia	8		5
Myrsine		4	2
Nothofagus fusca type			2
cf. *Ophioglossum*		2	
Phyllocladus			11

Pollen Type	Haast Gully No. 1	Rangitata Gorge No. 2 (Upper)	Rangitata Gorge No. 3 (Lower)
Phormium		2	
Plagianthus			2
Plantago	2		
**Podocarpus*		44	10
P. spicatus			3
Pseudopanax			2
Pseudowintera			2
Rosaceae		4	7
Trilete		6	3
Umbelliferae	11		
Unidentified	4	32	5
Unidentified *tricolpate*		8	10

* Reworked from Tertiary or older.

tr Less than 1%.

The samples were not rich in pollen. No. 1 from Haast Gully was richest and a total of 214 pollen grains were counted in five traverses. Two, not included in the sum, were Tertiary types. It could well represent a late-glacial pollen spectrum.

No. 2 produced a total of 50 grains (excluding aquatics and spores) in five traverses, and of these a good number were reworked Tertiary or older. These would include *Dacrydiumites*, *Microcachryidites*, at least some of the *Podocarpus* types, at least one unidentified tricolporate grain thought to be *Proteacidites*, and at least some listed as unidentified. This sample also had many of the pollen grains badly distorted or corroded. Interpretation is difficult. It presumably represents a cold phase with reworked pollen grains mixed in with more recent pollen types.

No. 3 was also poor in pollen (61 grains excluding aquatics and spores (*Isoetes* etc.). However, there were fewer obviously reworked grains, and distortion or corrosion was not severe. It is clearly water laid. This is indicated by the *Isoetes* spores which are sometimes frequent in the colder phases of the postglacial, in the late-glacial, and in the early transition stages of glacial/interglacial. The absence of reworked grains and the generally better preservation of grains compared with those in No. 2 suggest less extreme conditions, and the relatively high number of shrub types suggests this too, unless they too are reworked (e.g. the *Pseudowintera* from older Quaternary sediments.

APPENDIX 2

LATE QUATERNARY FAULT TRACES

Two prominent fault traces are mapped in the Mesopotamia and Lake Heron basins.

In the Mesopotamia basin a fault trace can be followed for 2 km north-east from grid ref. Map 2, J36/421232, S80/487387 - J36/438242, S80/505395. Movement has been vertical, the southern side being upthrown approximately 17 m. It cuts landforms of the Spider Lakes Advance, including those formed during the final retreat phase. It is thus interpreted as a Holocene feature.

In the Lake Heron basin a prominent fault trace is visible running north-south for 9.8 km from near Johnstone Stream (Map 1, J35/603417, S81/689583) to near Spider Lakes (Map 3, J36/582320, S81/655477). Movement has again been vertical with the western side being upthrown. The fault cuts landforms of the Trinity, Emily, Hakatere and Spider Lakes advances, as well as recent river terraces. Displacement is not uniform along the fault trace, increasing from north-south. Vertical displacement is difficult to measure accurately as reference points are hard to identify, particularly on moraines. In places the fault runs parallel to the general trend of the landforms with moraine on one side and outwash on the other. For these reasons the measurements given below are only approximate.

At grid ref. J35/604405, S81/690569 Emily moraine is offset 8 m. At grid ref. J35/595349, S81/668510 Trinity outwash is offset 25 m, and 2 km south the Paddle Hill Creek surface, which is here post-Spider Lakes in age, is offset 35 m. At the southern end of the fault the Spider Lakes 3 moraine is displaced 20 m. Along its whole length, the fault rarely has a well defined scarp in excess of 5 m. Displacement is in a number of small scarps, or occurs across a zone 100-300 m wide with no obvious scarps. Across the Paddle Hill Creek surface, fault traces are visible over a zone 0.4 km wide. Scarpletts range from 0.5 m - 3 m high.

Interpretation of the age of movement is difficult. The number of fresh scarpletts indicate movement is probably continuing. Although the fault cuts landforms of many ages, older landforms do not show progressively more displacement. Variations in offset presumably relate to the nature of the actual fault movement, and this has probably occurred mostly during the Holocene.